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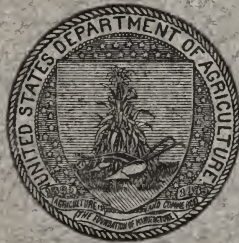
U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

FORECASTING FROST IN THE NORTH
PACIFIC STATES.

BY

EDWARD A. BEALS,
DISTRICT FORECASTER.

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU, OFFICE OF THE CHIEF.
Washington, D. C., December 2, 1911.

The honorable SECRETARY OF AGRICULTURE.

SIR: I have the honor to transmit herewith a paper entitled "Forecasting Frost in the North Pacific States," which has been prepared by Mr. Edward A. Beals, district forecaster of the Weather Bureau.

The paper describes the evolution of the system of frost warnings for the protection of fruit in Washington, Oregon, and Idaho, and contains detailed reports of the conditions under which warnings were issued during the critical season in the spring of 1911 for the fruit districts of Boise, Lewiston, Rogue River Valley, and Yakima Valley. It discusses the meteorological conditions which afford an indication of the probable occurrence of frost and on which warnings may be based. The paper is accompanied by three illustrations showing Weather Bureau equipment for observing temperature conditions, sketches of the four fruit districts mentioned, five weather maps showing the conditions preceding frost, and a chart of composite thermograph curves.

It is thought that the paper contains valuable information to the fruit growers in the States named, and it is therefore recommended that an edition of 2,500 copies be issued for distribution in those regions.

Very respectfully, your obedient servant,

WILLIS L. MOORE,
Chief United States Weather Bureau.

Approved.

JAMES WILSON, *Secretary.*

FORECASTING FROST IN THE NORTH PACIFIC STATES

By EDWARD A. BEALS.

Historical.—According to Boussingault, the celebrated French chemist, smudges have been used for centuries on the plains of Cusco on still clear nights by Indians to retard the loss of heat from the soil, and it is thought that the same or similar methods have been used in Europe for an equally long period. It is only in recent years, however, that the matter of frost protection has been scientifically investigated, and for literature on the subject the reader is referred to Farmers' Bulletin No. 104, Bulletin T, published by the Weather Bureau, and to various articles in the Monthly Weather Review.

Fruit raising in the north Pacific States has increased enormously in the last few years, and the number of trees that will come into bearing in the next five or six years will increase the acreage at least tenfold. In the early days of the industry the principal crop was prunes, and the large orchards were mostly in the humid sections of Oregon and Washington. There were very few large apple and peach orchards, and those in bearing were nearly all located where the air drainage was good and the losses by spring frosts were infrequent. In the case of prunes many of the growers believed that when they had short crops the damage was done by cold rains during the blossoming period, which prevented the bees from carrying pollen to the stigmata, and the fruit did not set on that account, rather than because of injury by frost.

For these reasons very few growers a few years ago made any attempt to protect their orchards from frost, and those that did were not very successful, as their methods were crude, and where the necessity was greatest the orchards were badly located and the task was almost hopeless from the start. Frost warnings were issued by the Weather Bureau during this time, although very little attention was paid to them, as foreknowledge of frost is of practically no benefit to the horticulturist unless he is prepared to protect his crop from threatened injury.

In 1907 Mr. P. J. O'Gara, one of the scientific assistants in the Bureau of Plant Industry, was sent to the Rogue River Valley to study the pear blight, which was making inroads among the pear

and Spitzenberg apple trees in that section of the country. He quickly realized that the fruit growers were losing much more fruit by spring frosts than they were willing to acknowledge, and being familiar with orchard-heating methods in California, he soon induced a number of orchardists to adopt similar methods in the Rogue River Valley. The plan was so successful the first year that it was tried the next on a fairly large scale and with even greater success. In the meanwhile a few orchardists in other important sections had taken up this work, and by the spring of 1910 the movement had obtained large proportions in four important fruit centers, viz, Rogue River Valley, Yakima Valley, Lewiston orchard district, and the Boise orchard district.

As soon as an orchardist was prepared to heat his orchard the question of accurate frost warnings became of paramount importance, and as the number increased the question became accentuated. The owners and managers of these orchards had gone to the expense of thousands of dollars for material to insure their crops from damage by frost, and they were not satisfied with a warning classified as a light or a heavy frost, where in the one case the minimum temperature in a standard thermometer shelter was expected to remain above 32° and in the other sink below that point. They want to know just how cold it will get and just when it will be necessary to start their fires. They also want this information as far ahead of each impending frost as possible.

The district forecaster had been making forecasts of light and heavy frosts, basing his verifications upon thermometer readings at Weather Bureau reporting stations; those for the Rogue River Valley being based upon reports received from Roseburg, Marshfield, and Siskiyou, all some distance away and where the thermometers were exposed in shelters at different elevations above the ground; those for Boise upon reports from readings taken in an instrument shelter on the roof, 78 feet above the ground; those at Lewiston over sod, 10 feet above the ground; and those for Yakima from the station at Walla Walla with thermometers located on the roof, 62 feet above the ground.

These irregular exposures which in some cases were many miles from the place where we were to look for accuracy in results made it necessary to weigh the forecasts by further estimates as to the differences that would probably prevail between the temperatures at the reporting stations and those in the orchards being protected. We could obtain average differences by studying the cooperative observer's records at near-by stations, but these were unsatisfactory, and it was soon found that to get best results we had to put stations in the heart of the orchard districts, and then there were large differences to be calculated at places not very far apart.

Accordingly, early in 1911 the Chief of the Weather Bureau authorized the writer to make an investigation of the subject with a view to localizing the work and improving the forecasts. The foregoing four localities were selected for the first year's work and a number of "key" stations were established in the heart of the different districts. (See Fig. I, Fig. II, and Fig. III.) It was necessary to employ temporary observers to look after the "key" stations and to send a trained man to North Yakima to look after the work in that valley. In the Rogue River Valley we were fortunate in securing the services of Mr. P. J. O'Gara, who had made a special study of the frost conditions in that section and was familiar with the topography in every orchard for many miles around Medford, Oreg.



FIG. I.—"Key" station, Boise, Idaho.

An abstract of the reports from the different localized centers follows:

Medford (by Mr. P. J. O'Gara)* (See Diagram A.)—We have had a hard pull of it, but in every case where the growers had properly prepared for the fight they have won out. A careful examination of the orchards above the valley floor shows scarcely any damage excepting in some peaches and the Bosc pears, which are most easily injured. However, even the Bosc pears will have quite a good crop. On the valley floor, especially during the mornings of April 14, 15, and 29, the fight was a hard one. However, the lowest drop of 22° to 24° was for such a short time that, in the main, 25° and 26° were the temperatures

against which we were contending. The fact that there was little or no wind movement was a tremendous advantage to those heating the orchards. The loss



FIG. II.—“Key” station, Lewiston Orchards, Lewiston, Idaho.



FIG. III.—“Key” station, Parkers Bottom, Yakima Valley, Wash.

on the valley floor is very light, because practically all the growers who had anything to save did their work. Two or three were not fully equipped, but it

was not because they had not been advised better. They had their own way about it in the matter of the number of fires, and now they see their folly. At this time it looks as though we are to have a better pear crop than last year.

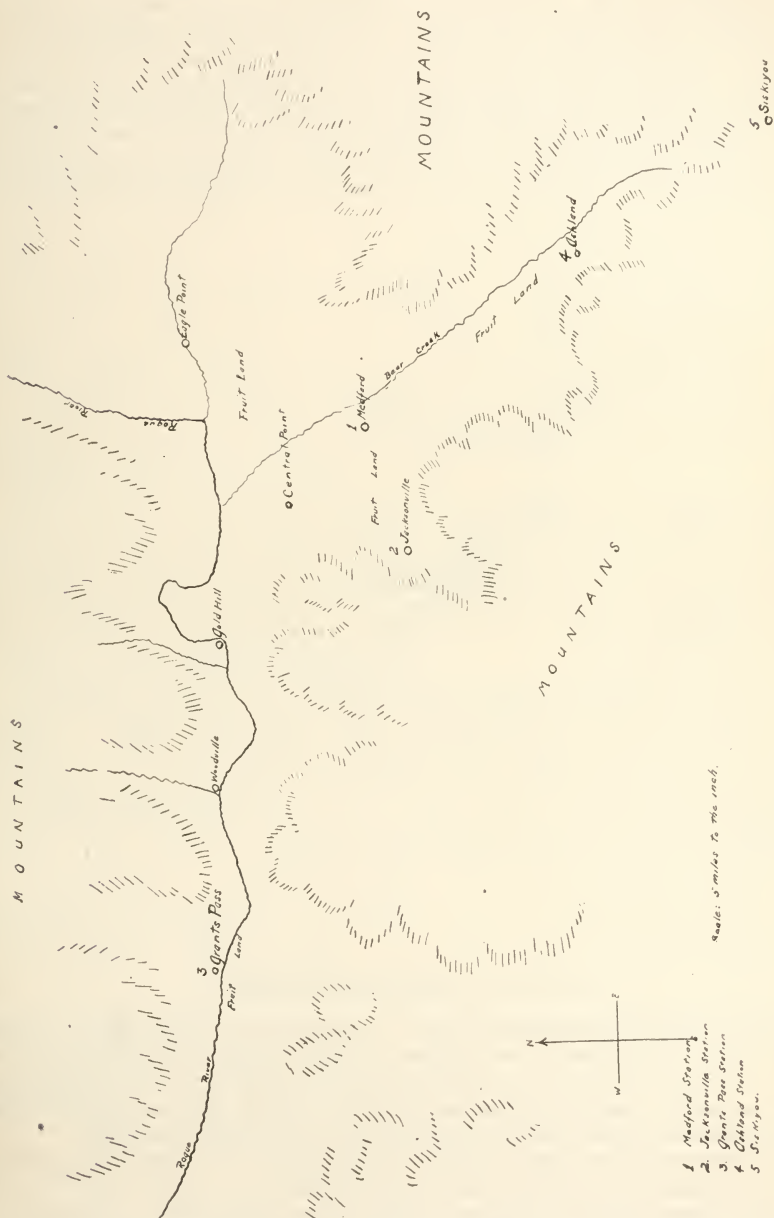


DIAGRAM A.—Rogue River Valley fruit district.

The apples bloomed very light, and any shortage of the apple crop may be attributed to this cause.

The fruit growers one and all appreciate our work. From April 10 to 16, inclusive, I did not take off my clothes. There was so much anxiety on the part

of everyone that I felt it my duty to stay up night and day and help the growers out. On the mornings of the 11th, 12th, and 13th I was very much afraid the growers would waste their fuel unnecessarily, and knowing the possible chances for much lower temperatures on the following days, namely, the 14th and 15th, I constantly urged them by telephone to refrain from firing whenever the temperature ranged no lower than 29° in the orchards. The saving of fuel proved to be the saving of the crops, because many had not laid in a supply for more than three firings. In instructing them to fire I had them light only as many fires or pots as would hold the temperature above danger. The local forecasts were very accurate both as to time and minimum temperature to be expected. I always indicated the time it would be necessary to begin firing and had the

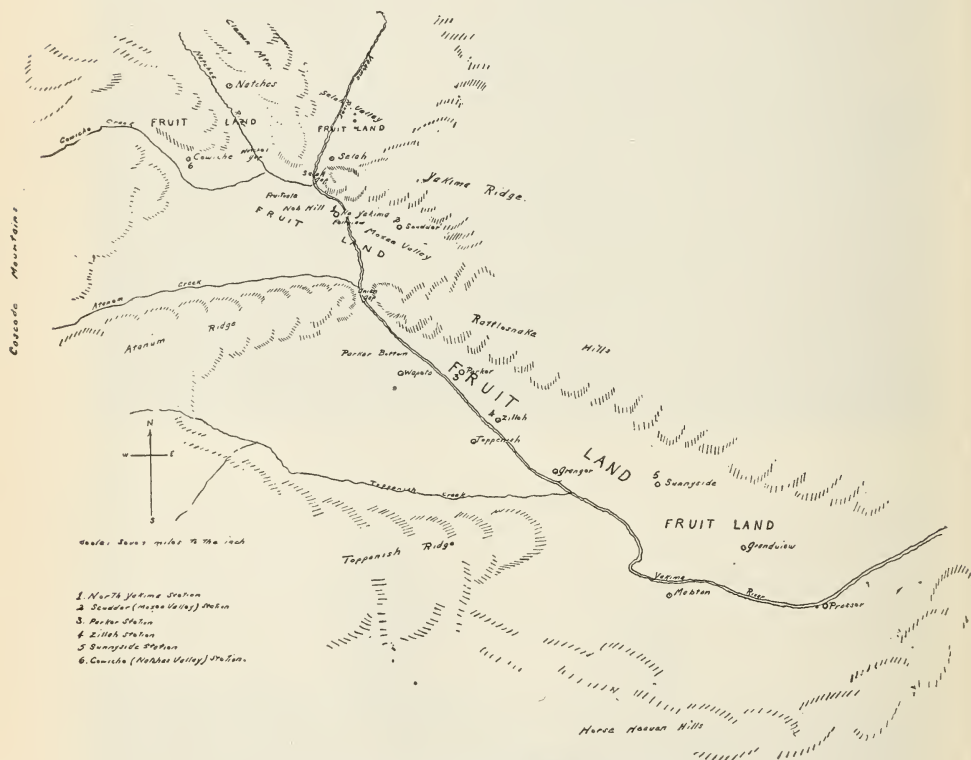


DIAGRAM B.—Yakima Valley fruit district.

growers set their alarms for that hour. In many cases I called them up during the early morning hours to warn them of their danger. We believe we have been successful, and although a few have lost some fruit, it is not because of any fault of ours. The instructions as to how to prepare were all that previous experience had taught us, and the forecasts were timely and accurate.

It is rather early to estimate what we have saved, but a half million dollars will not be far from the gross value saved this year.

North Yakima (by Mr. Thomas R. Reed). (See Diagram B.)—The work of protecting orchards against freezing temperatures by artificial means has been practiced for only a few years in the Yakima Valley—two I think—in the lower, and this season is the first in the upper valley. With many, therefore, it is still

in its experimental stages, while with others the work has become an established feature of annual occurrence. The number who fire their orchards has increased each year since the work began and it is safe to say that after this season's experience a vastly larger number will prepare to protect their blossoms than ever before.

The issuance of accurate predictions is a matter of vital importance to these people and the demand for the forecasts during last season has fully justified the newly inaugurated service of the Weather Bureau. The warnings have been distributed to the public from the exchanges of the Pacific Telephone & Telegraph Co. and the Yakima Valley Telephone Co. Manager Jones of the former and Manager Bartholomew of the latter have been courteous in lending us their cooperation. Warnings were issued for the following places: North Yakima, Moxee, Parker, Zillah, and Sunnyside, and were placed on the following exchanges: North Yakima, Wapato, Toppenish, Zillah, Granger, Sunnyside, Grandview, Prosser, Mabton, and Pasco. Forecasts were attempted for the first five named stations only, because observational data were procurable from these. The first two and the last, i. e., North Yakima, Moxee, and Sunnyside, are regular reporting cooperative stations of the Weather Bureau; Parker and Zillah stations were specially established for the work this spring. All stations were equipped with standard maximum and minimum thermometers; the North Yakima, Parker, and Sunnyside stations with exposed thermometers, and all except Parker with rain gauges.

Regular telephone reports of temperature and weather were received from these stations and from the Reclamation Service station at "Tieton headquarters" in the Naches Valley. The Reclamation Service officials have been particularly ready to respond to any requests made upon them for assistance, and Mr. Remington of Sunnyside and Mr. Nolan at Tieton headquarters deserve credit for the regularity with which they have forwarded messages each evening from their respective stations.

The meteorological conditions favorable for frost in the Yakima Valley include the usual conditions of high barometer following a spell of cloudy, cold weather in which the soil has lost its accumulated heat, clear sky, and very light or no wind. It is considered by local observers that frost is most likely to follow a period of bad weather and the shift of wind from the south or southwest into the northwest or north. It is popularly supposed that danger of frost is small unless the veering to northerly quarters has been preceded by quite a marked period of southerly wind. This of course may be a colloquial way of indicating the necessary intensity and duration of the cyclonic low occupying the northwest; but it is worthy of note that judging from observations this season, dangerous frost is not likely except following protracted cloudy and cold weather, and that all the really serious frosts of the season have followed days on which the maximum temperature has been under 65° and the current temperature under 60° at the time of the afternoon observation.

High barometer alone, while causing frost in other localities in the State, has repeatedly failed to bring freezing temperatures to this valley, attributable partly, perhaps, to active air movement often occurring in connection with anti-cyclonic weather. A freeze may occur here when the Northwest is occupied by low pressure; in fact, when a rain forecast would seem more legitimate than a frost warning, as on the night of the 6th of April; but this is an uncommon condition. Under such conditions the barometer may show no fluctuations worth speaking of, the surface currents may be from the south, in fact nothing to warrant a frost warning being issued except the fact of a clearing sky and a sharp fall in temperature.

The forecaster has then to determine whether the wind is to remain light and the sky clear, and this is an extremely precarious undertaking. Perhaps the diurnal rise in the barometer occurring at the time his decision is being made adds to the difficulty; and he must be able to distinguish to a certain extent between the periodic and the unperiodic movement, for it is the latter upon which he depends in a large measure to foretell the condition of the sky. Under such conditions, and unless the forecaster is sure of his position, it is wiser to place on their guard those who wish to protect their orchards, for the growers would rather be warned a few times unnecessarily than to have freezing temperatures descend on their orchards without forewarning.

The freeze occurring on the morning of April 6, when the temperature at North Yakima dropped to 25° , could scarcely be foreseen, either from the weather map or from local observations, but it is a type of local freeze which should be studied and for which the local observer should be constantly on guard. Although on this occasion the warning for North Yakima was for light frost only, no one failed to fire. Warnings for Moxee, Zillah, and Sunnyside were for freezing temperatures and firing was general throughout the lower valley. Much injury was sustained by unsmudged orchards and some orchards were injured where sufficient pots were not in use.

The ensuing freezes, which occurred with unusual frequency and severity for this section, were more easily foreseen. Between the inclusive dates of April 5 and 15 nine heavy frosts were recorded in North Yakima, and during the first half of the month there were more than this number in the neighborhood of Moxee and on the low ground below Union Gap. Seven times the minimum temperature dropped to 28° or lower at the North Yakima station. The severest freeze of the entire period occurred on the morning of the 13th of April. The North Yakima station registered 24° ; in Moxee 16° was reached, and the temperature in the lower valley ranged from 17° at Sunnyside to 28° at Parker Heights. This freeze ended the firing for the season with a large number of orchardists, for attempts to cope with such conditions were futile, except on topographically favored land. On the higher lands, however, especially in the Parker Heights and Zillah districts, much fruit was saved by firing.

On the two mornings following what was very nearly a repetition of the phenomenal temperatures of the 13th was experienced. Orchardists prepared for only three nights' firing were required to procure more oil and those depending on the supply in North Yakima were unable to do so, as the amount there was insufficient. The big storage tanks in the lower valley, especially at Granger, Wapato, Outlook, and other points, enabled the growers to continue the orchard firing until the last freeze was past. It was undoubtedly a strenuous period for the fruit men and one which is not likely to be repeated for many years. It showed the necessity of using an ample number of smudge pots and also the value of orchard firing on a large scale, showing the greater ease of heating a large district than a small one, or one in which heating is practiced only in a sporadic way.

North Yakima men were unsuccessful in maintaining safe temperatures, partly because they used too few pots—generally about 40 or 50 to the acre—and partly because each heated orchard was surrounded by unheated ones, and the wind, which was a feature of several frosty nights, effected a dispersion of heat and smoke. When practically all the orchardists fire, windy conditions can much better be coped with. On the morning of the 11th in particular orchardists reported that whereas under ordinary circumstances they could raise the temperature 6° to 7° with 55 pots to the acre, on this morning

it could only be raised 3°. On the south slope of Nob Hill the smoke blew rapidly away, scarcely reaching the lower branches of the trees.

It was on this night (10th-11th) that the severest freeze occurred in the Nob Hill and Fruitvale districts, which are generally least affected by frost, the former being considered immune. The thermometer in the Weather Bureau shelter in North Yakima registered 29° and in Moxee 28°; 31° was reported from Parker, 28° from Zillah, and 33° from Sunnyside. That conditions as usually experienced suffered a complete reversal will be seen when it is stated that the temperature on Nob Hill and Fruitvale varied between 20° and 23°. The reports from these districts showed much uniformity and many readings were made from reliable instruments. Moxee—notoriously cold—varied only a degree from North Yakima, and Sunnyside, which more often corresponds with Moxee, was even warmer. An interesting problem is here presented and its solution may disclose some interesting facts. The following is suggested by observations this spring:

A study of a topographic map of the region should be made in order to appreciate the situation. The Yakima Valley is inclosed on all sides by mountain ranges varying from 2,500 to 3,000 feet in height and higher in the Cascades to the west. Access is had to the valley by two gaps on the north and one on the south. Nocturnal air drainage will always be from north to south under normal conditions, following the slope of the land, and observations show this actually to be the case. Fruitvale and the northern slope of Nob Hill are the first to benefit by the northwest breeze from the Naches Canyon, as they lie directly in its course and in close proximity to the Naches Gap, from which it issues. There may be a similar breeze from Selah Gap, a little to the eastward, but observations do not cover this point, nor are there any extensive orchards in line with Selah Gap to benefit by such a breeze if there were one.

The Naches Valley above Naches Gap forms a natural reservoir for the air drainage from a vast mountainous area, and it is natural to conclude that when the convergent air is expelled into the Yakima Valley below through the outlet formed by Naches Gap a mixing of the air and possibly an adiabatic warming ensues, which would account for the comparatively higher temperatures encountered in the region lying directly in its path, as at Fruitvale, and the comparatively lower temperatures in the Fairview and Moxee districts, which lie several miles southeast of Fruitvale.

The Weather Bureau station is located in the city of North Yakima, and, therefore, between the two districts under discussion, Fruitvale being northwest of the city and Fairview and Moxee southeast. The thermometer at this station strikes a pretty fair mean, for while Fairview is often 2° and Moxee 5° to 8° colder than the North Yakima station, Fruitvale is usually a few degrees warmer. As the breeze from Selah Gap spreads out and flows across the valley it loses its force, its temperature is lowered by radiation, and with further southeastward movement its character is changed from a protective wind to a more or less destructive one.

On the morning of the 11th, when the conditions in these districts reversed, a freezing wind was blowing from the south and southwest, having blown from this quarter throughout the night. There was no counter breeze from Naches Gap, and the minimum temperature reported from the Naches Valley above, a district from which comparatively high temperatures are usually looked for, was 22°. Thus it appears that strong connection exists between a reversal of the customary wind direction and a reversal of temperature conditions in the several localities under discussion.

I would recommend the resumption of the "key" stations at Parker, Zillah, and Sunnyside next season, and also that a station be placed in Grandview or Prosser to report daily by mail, for if forecasts are to be issued for these districts it will be necessary to have data from them.

Some of the telephone exchanges, as at Zillah and Granger, for instance, close at 9 p. m., so it is necessary to issue warnings as early as possible and avoid the necessity of modifying them at a later hour. An improvement can be effected in quicker transmission of the forecasts from Portland. It might be that by sending them by telephone they would be subject to less delay in transmission and could be placed before the public nearer 7 than 8 p. m.

In the past firing has been largely confined to the country below Union Gap, the number of pots in use being estimated at 70,000, 26,000 of this number being purchased this year. Many more orchardists in both lower and upper valleys will fire next season, and the forecaster will have greater opportunities for being of service to the individual orchardist than was possible this year. This year the field of maximum activity was rather remote and personal advice on critical nights was not feasible. However, those above the Gap kept in touch with me as long as they continued to fire and made things pretty lively. The forecasts gave general satisfaction this year in spite of its being the first year's work and performed somewhat blindly in the absence of reliable data. The work should be much easier next year and in succeeding years as local observational data accumulate and experience is acquired. A feature of the work very valuable to the fruit men is the morning forecast during protracted frost spells, for by it the grower is advised as to the need of hauling oil before nightfall.

Firing above the Gap was practiced for practically the first time this year. It resulted in a general failure to maintain a temperature of anything near 28°, and the orchardist learned the lesson that too few pots are worse than none at all, since they do not save the fruit and are a great expense.

In many orchards, on the night of the 11th-12th, the temperature had fallen to 28° by midnight, remaining below that point for seven hours; and to save the crop it would have been necessary to start a reserve number of pots before daylight to replace those that had burned out. It is difficult to estimate the loss, for the reason that the crop this year was not expected to reach that of last by any means; it being an "off year." Mr. Thompson's estimate of 1,100 cars is generally conceded to be too low. Last year about 3,000 cars were sent out from the Yakima Valley, and the general belief is that the shipment this year will be in the neighborhood of 2,000, making the total value of the crop very close to \$1,500,000. Any estimate of the loss from frost is impossible at this date, for I have seen a full crop of apples, peaches, and pears in one orchard and found the entire crop destroyed in another close by. Every orchard in the valley would have to be examined to make a correct forecast of the losses by frost.

How many took advantage of the service it is not possible to say, but the girl who handled the forecast distribution says that she was literally swamped with calls between 7 p. m. and 9 p. m. on critical nights. Since this interest was manifested by those who do not fire, it is easy to see what would be the interest taken by the increasing number who expect to engage in orchard protection in succeeding years. Beyond question it is desired to have the newly inaugurated frost service continued next season. It has required the first season to wake up the people to their part in the work, and to the value of orchard heating even in comparatively safe districts; next year will witness their greater dependency on the Weather Bureau service, and greater accuracy and assurance on the part of the forecaster assigned to this locality.

Boise (by Mr. Edward L. Wells). (See diagram C.)—The Boise Valley is well suited to the growing of such fruits as apples, pears, prunes, sour cherries, and common berries. Some fruit has been grown in the valley for many years, but it is only within the last few years that scientific fruit growing on a commercial scale has become an important industry.

While the entire region is more or less subject to spring frosts these frosts are rarely sufficiently severe to cause widespread damage. For this reason, prior to 1909, comparatively little attention was given to measures to protect fruit from frost injury. The spring of 1909 was one noted for a succession of damaging frosts, resulting in almost a complete failure in many orchards. This failure turned the attention of the growers toward protective measures, and some of the more progressive of them provided themselves with oil pots and

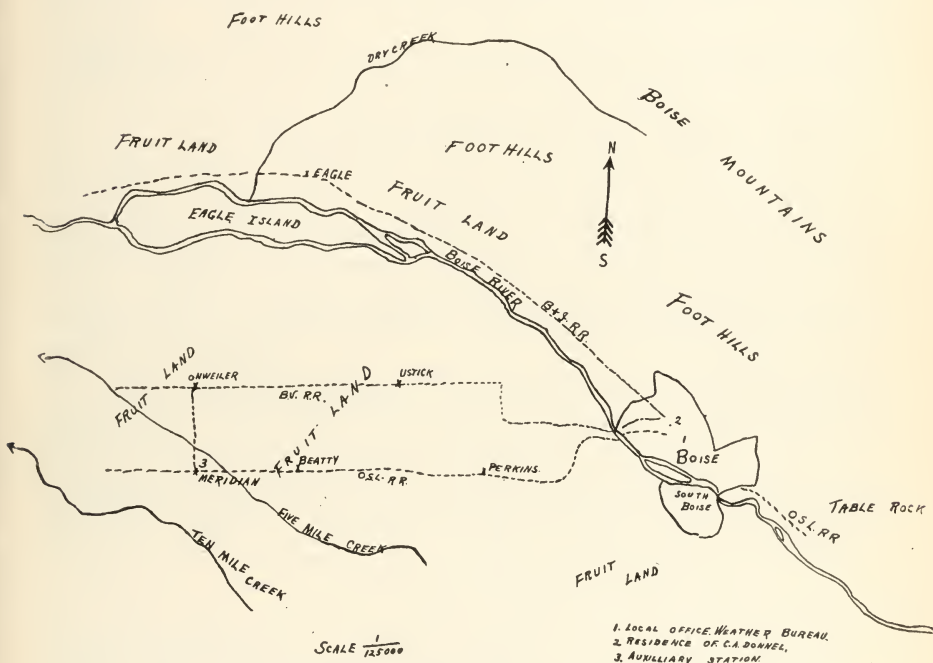


DIAGRAM C.—Boise Valley fruit district.

oil for use in 1910. The spring of 1910 was much more favorable for fruit than that of 1909, so much so that there was a good yield of fruit in most of the unprotected orchards, as well as in those that were protected. This being true, there was little increase in 1911 over the area heated in 1910; the entire area in the upper part of the valley adjacent to Boise probably not exceeding 1,000 acres. Like that of 1910, the spring of 1911 was not a good one to demonstrate the efficiency of protective measures, for while some very low temperatures were experienced, these low temperatures occurred when the buds were least susceptible to injury, and little damage occurred that could be directly traced to frosts.

It is probable that orchard heating will not become common in this valley as it is in the Grand Valley in Colorado and in the Rogue River region in Oregon, until another season like that of 1909 is experienced, when the practical value of heating can be demonstrated. It is believed, however, that the time will come when orchard heating will become general in the Boise and neighbor-

ing valleys, and the Weather Bureau should anticipate the demand for accurate information that this condition will bring about by enlarging the number of auxiliary stations and carefully studying the frost problems in every locality where fruit is grown.

The topography of this region is peculiar and gives rise to some weather conditions that make frost forecasting a difficult matter. The Boise River, in its upper reaches, flows through a rugged mountainous region. About 6 miles southeast of Boise it emerges from a deep box canyon, the mouth of which marks the head of what is known as the Boise Valley, which extends thence northwestward with increasing width toward the Snake River. Northeast of Boise are the Boise Mountains, reaching in 12 miles an elevation of 7,500 feet, or 4,800 feet above the city. Toward the southwest the ground rises in a series of widening benches. Through this bench land, where most of the large orchards are located, run several water courses, rather unimportant naturally, but forming a means for air and water drainage, and apparently playing an important part in determining local temperatures on frosty nights. The entire region may be classed as arid, having approximately 13 inches of precipitation annually at Boise, and somewhat less at points away from the mountains. Water for irrigation is supplied by the Boise River.

In fair weather there is quite a noticeable mountain and valley breeze blowing down the valley, or from the southeast from early morning to about 10 a. m., and up the valley or from the northwest in the afternoon. Frosts occur ordinarily upon the approach of a strong high-pressure area from the northwest. The outflow from this high, combined with the ascending currents already mentioned, make a strong northwesterly wind in the afternoon, which has come to be considered as the surest indication of frost. At night, in addition to the ordinary nocturnal lessening of the wind velocity, the descending current opposes the outflow from the high, causing a stagnation of the air highly favorable for the occurrence of low temperatures near the ground. At such times there is a noticeable tendency for the colder air to settle into the shallow depressions along the water courses already mentioned. When conditions for rapid radiation are particularly favorable no two thermometers in the valley will indicate the same temperature. At other times the distribution of temperature is fairly uniform. Whenever there is any considerable amount of wind at night frost does not occur.

TABLE I.—*Frost observations, Boise, Idaho, 1911.*

Date.	Lawn temperature, Boise, 8 p. m.	Dew point, Boise, 8 p. m.	Relative humidity, Boise, 8 p. m.	Dew point, Boise, 5.20 p. m.	Dew point, Meridian, 5.40 p. m.	Expected minimum temperature.	Minimum temperature, Boise, following.	Minimum temperature, Meridian, following.
Apr. 12.....	32	25	73	26	21	20	20	18
13.....	38	26	59	11	10	22	21	20
13.....	¹ 36	¹ 18	¹ 45	.....	.....	.....	.....	.....
14.....	46	16	27	10	10	26	26	28
16.....	54	28	37	22	20	32	28	35
21.....	51	33	50	28	32	.....	33	30
May 6.....	52	32	47	28	32	30	36	39
8.....	53	32	44	38	36	32	30	32
9.....	49	30	47	28	25	26	30	29
10.....	53	34	43	34	34	30	35	34
19.....	52	38	61	41	35	32	33	32
24.....	53	34	49	31	32	² 32	31	31
25.....	53	32	44	28	32	30	33	37
26.....	52	38	58	36	37	34	34	34
27.....	57	32	38	32	32	32	34	35
June 4.....	60	32	36	27	33	33	37	36
Mean.....	.....	30	.....	28	28.1	29.4	30.7	31.3

¹ Taken at 10 p. m.

² Not given out. No warning received.

Sometimes when the crest of the high reaches or passes this region before morning an easterly wind will spring up. A brisk easterly wind, coming as it does off the mountain range, partakes of the nature of a chinook. Usually the effect of these chinooks is hardly noticeable except over Boise and the belt of land lying between the foothills and the river. Sometimes, however, the effect becomes noticeable on the bench lands, and on rare instances the chinook has been known to pass over the city and materially affect the temperature on the bench.

It has long been known that the temperature record made from instruments exposed on the roof of the Government building, 78 feet above the ground, failed to represent conditions as experienced in the orchards. It was known first that on clear, still nights the temperature in the orchards fell to a lower point than that indicated by the roof instruments. It was known also that the dew point as found on the roof gave no index of the expected minimum temperature.

During September, 1910, a record was kept by means of instruments exposed in a cotton-region shelter mounted on the lawn in the rear of the Government building. It was found that the dew point and the following minimum temperatures at this exposure correspond very closely, the minimum being somewhat higher than the 8 p. m. dew point, except when the 8 p. m. relative humidity was above 55 per cent, in which event the minimum was somewhat below the dew point. Later the shelter and maximum and minimum thermometers were removed to the residence of Mr. C. A. Donnel, assistant observer, at 1711 Washington Street, where a record has been kept continuously since January 1, 1911. During the same period a record has been kept at Meridian, a village 10 miles west of Boise, the instruments at the two places having practically the same exposure.

It has been found that during the winter months the mean temperature at the two places is almost the same, but the range is slightly greater at Meridian. Beginning with April, however, the mean maximum and mean minimum at the two places are practically identical. The temperature goes slightly lower at Boise on cold nights and is slightly higher on warm nights.

Beginning with April 1 Meridian was supplied with an exposed thermometer, thermograph, and sling psychrometer in addition to the maximum and minimum thermometers already in use, and the dew-point observations were made daily at about 5.40 p. m., and occasionally at about 8 a. m., till June 15. At the same time dew-point observations were made daily at about 5.20 p. m., and on cold nights at about 8 p. m., on the lawn in the rear of the Government buildings at Boise. The data from both early observations were embodied in the p. m. report sent to Portland at 6 p. m.

At the beginning of the season the ordinary frost warnings from Portland were supplemented by detailed statements of expected conditions as indicated by the afternoon reports. Later this service was discontinued, presumably because of the absence of the district forecaster. These special reports were adapted to the orchard region by the official in charge at Boise and given to the telephone exchanges for distribution and to all interested persons asking for information. The office was kept open for information part or all of every cold night during the season.

For purpose of study a table has been made up (see Table I) giving for cold nights only (a) the lawn temperature at Boise at 8 p. m.; (b) the lawn dew point at Boise at 8 p. m.; (c) the lawn relative humidity at Boise at 8 p. m.; (d) the dew point at Boise at about 5.20 p. m.; (e) the dew point at Meridian at about 5.40 p. m.; (f) the expected minimum temperature as given

out to the public: (g) the following minimum temperature at the residence of Mr. C. A. Donnel, 1711 Washington Street; and (h) the following minimum temperature at Meridian.

It appears from this table, first, that the auxiliary station at Meridian is not needed for the purpose of dew-point observations, the lawn dew-point readings at Boise furnishing practically identical data; second, that the 5.20 p. m. reading, made before taking the regular observation, is too early for best results in the spring; third, that the 8 p. m. dew point on the lawn forms an excellent indication of the expected minimum temperature near the ground when taken into consideration together with the relative humidity and other local conditions. It will be seen that the minimum temperature falls below the lawn dew point when the humidity is high and is relatively higher when the humidity is low.

The experience of the season has shown that it is possible to make a very close forecast of the minimum temperature for a given place. When, however, the forecaster is confronted with the task of advising each grower what temperature to expect in his orchard, the problem becomes much more complex. For instance, on April 13, when the temperature fell to 20° at Mr. Donnel's residence at Boise and to 18° at Meridian, some standard thermometers used by the growers went as low as 12°. Again, on May 25, when the ground temperature at Boise and Meridian alike was 31°, some orchard temperatures as low as 25° were reported. Just how much of this difference is due to topography and how much to faulty exposure it is difficult to say. Some of the growers believe that the Meridian temperatures were too high, owing to the fact that the station was in town. However, as there are no large buildings in the town and no buildings of any kind near the shelter, it is evident that this is not true.

It is probable that the fact that the growers' thermometers are exposed without sufficient shelter, and are therefore subject to error from excessive radiation, may account for the discrepancy. Mr. C. A. Donnel spent the night of May 10-11 in the orchard district making comparative readings, with a view to determine how important this factor was, but the temperature was fluctuating considerably and, without assistance, it was difficult to secure accurate results, and, owing to insufficient office help, no further attention could be given this during the season. From such data as he was able to obtain it is apparent that freely exposed thermometers read from 2° to 3° below the true air temperature. This leaves some little difference to be accounted for by topography.

Lewiston (by Mr. W. W. Thomas). (See Diagram D.)—As has been the custom at this station in past years, the daily papers in Lewiston and the weekly in Clarkston published notices in different issues prior to the beginning of the frost season to the effect that all fruit growers should register their names and telephone numbers at the local office of the Weather Bureau. At the beginning of the season our frost-warning list, made up of the names thus registered, contained the names of all the growers in this district who desired to protect their orchards in any way against frost damage and who could be reached by telephone or otherwise.

The public was also informed through the local press that thermometers would be compared with a standard thermometer at the Weather Bureau station free of charge. A number of growers availed themselves of this opportunity, and upward of 50 thermometers were tested and the owners furnished with cards showing the error at 32°.

For the purpose of a study of the temperature conditions at different points in the valley a temperature station was established in a favorable location in the Clarkston (Wash.) section, 1½ miles southwest of the Weather Bureau sta-

tion. This station, known as "key" station A, was equipped with a standard set of maximum and minimum thermometers, an exposed thermometer, and a thermograph. It was placed in the orchard of Mr. J. H. Clear, who volunteered to take the desired observations. A similar station, known as "key" station B, was established 2 miles southeast of the Weather Bureau station, near the cen-

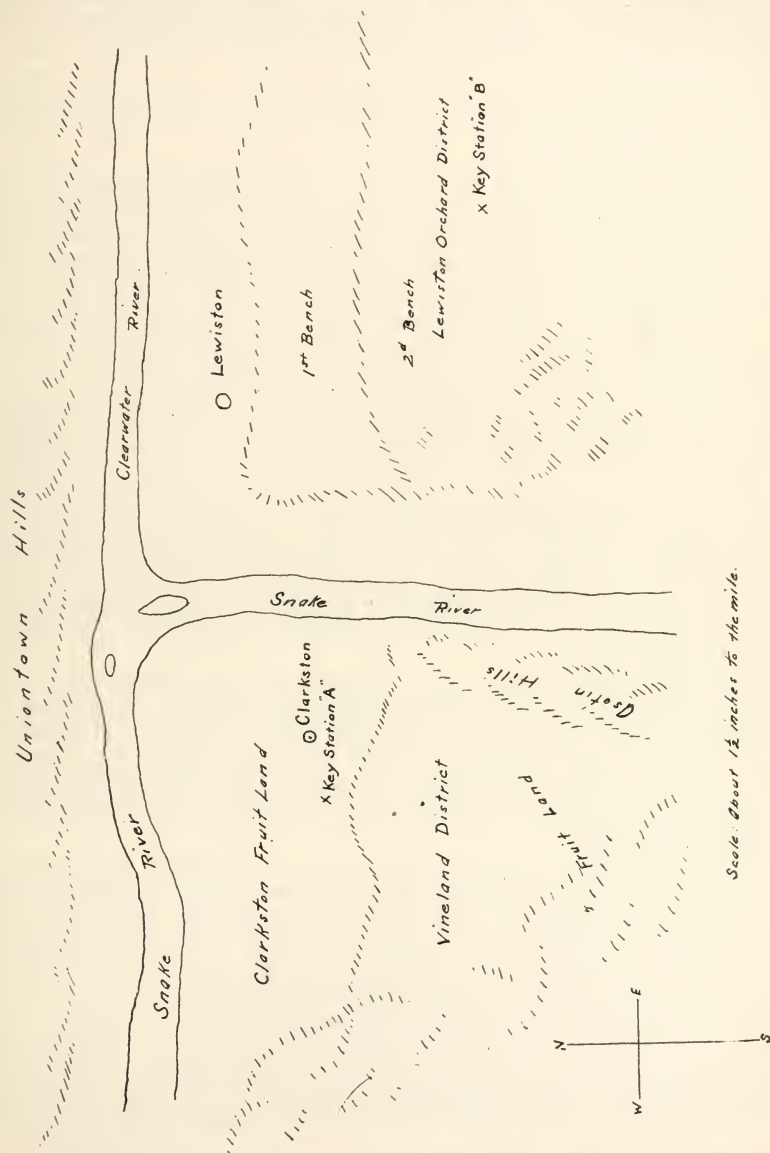


DIAGRAM D.—Lewiston-Clarkston fruit district.

ter of the present bearing orchards in the section known as Lewiston Orchards. It was placed at the home of Mr. P. W. Mullarky and was equipped with a set of Queen & Co.'s maximum and minimum thermometers and a Weather Bureau exposed thermometer. The elevation of station A is 850 feet and of station B 1,440 feet, and of the local Weather Bureau station 830 feet above sea level.

Owing to the fact that orchard heating had never been given a sufficient test in this valley to demonstrate its efficiency, the growers did not take it up to the extent that its usefulness in other fruit sections would seem to have warranted. However, a number of progressive orchardists provided themselves with fire pots and oil, either crude or slough distillate.

It is estimated that in the Clarkston section, where there are 2,000 acres in bearing trees, about 25 per cent of the orchards were provided with fire pots or heaters and about 10 per cent with smudge material, such as prunings, old straw, rubbish, etc.

Practically no frost-preventive measures were taken in the Lewiston orchards section, because in that section the trees were young and it was not desired to have them carry a full crop.

Frost warnings were issued from the office of the district forecaster at Portland, Oreg., and either accompanied the regular morning forecast or were sent out in the evening as supplemental forecasts based upon the afternoon telegraphic reports. These evening warnings usually included a forecast of the minimum temperature that might be expected the following morning, and were, for this reason, more valuable to the growers than the ordinary frost prediction that warns against light, heavy, or killing frost without indicating the probable degree of temperature that it might be necessary to combat.

The warnings received in the morning were distributed by mail and by telephone; those received in the evening by telephone only. By an arrangement with the local telephone company, the Weather Bureau was given the exclusive service of an operator at "central" during the time the warnings were being distributed. This operator kept in communication with the observer, and as soon as one grower was notified another was rung up. In this way it required but little more than an hour to distribute warnings to all growers on the frost-warning list. This method is much more satisfactory to the growers in this valley, as well as to the local station, than the one that is sometimes suggested, by which the warnings are given out by commercial clubs and by the operator at the telephone center.

The local office of the Weather Bureau did not stop at the distribution of the warnings simply. The office was kept open and available to all growers for information or advice at all hours throughout the frost period, and at critical times the observer or his assistant remained on duty all night. When the conditions threatened frost, the observer was kept informed as to the progress of the temperature, and when such action was warranted he instructed the growers to light their fires.

The fruit reached the full-bloom stage in the early days of April. During the first decade of that month there were some frost warnings issued and some frost temperatures occurred, but no heating was considered necessary, except on the morning of the 6th, when firing was general for two or three hours, ending at sunrise. The temperature on that morning fell to 30° at the Weather Bureau station and to 28° in some other places in the valley.

On April 11 adverse weather conditions set in, and on the morning of the 13th and again on the morning of the 14th the temperature was lower than ever before experienced in this valley so late in the season, the minimum at this station being 6° below freezing and in other portions of the valley from 8° to 10° below freezing. Coming, as they did, at a critical stage of the bloom, there was grave apprehension that these low temperatures had done much damage. For some time it was generally believed that all fruit was killed, except in those orchards where ample protective measures were taken. Two months after the freeze, however, the developing fruit told a different story. Conservative estimates places the peaches at about 60 per cent of a full crop

and cherries from 15 to 25 per cent, including both protected and unprotected orchards. It also shows a rather surprising situation as to the damage done, in that in a number of protected or heated orchards there will be few, if any, peaches and no cherries, while in some unprotected orchards there will be this year's average of both peaches and cherries.

The active work of the Weather Bureau during this frost campaign was eminently satisfactory and pleasing to the growers. All growers who were prepared in any way to protect their orchards were kept informed as to the current weather conditions and were amply warned of the approach of all the damaging temperatures that occurred. It is stated by competent authority that the work of the bureau in conjunction with that of the growers who heated their orchards has saved a quarter of a million dollars to the fruit industry in this valley this year.

From April 1 to May 15 observations were taken at the "key" stations and at the local Weather Bureau station at 5 p. m. daily and telegraphed to the district center at Portland, Oreg. In addition to these, special observations were taken daily at this station shortly after sunset. These consisted of the pressure, current temperature, dew point, direction and velocity of the wind, and the state of the weather. The object of these special observations was to discover, if possible, some relation between the dew point in the evening and the lowest temperature on the following morning. It was found that between these two quantities there existed no definite relation that could be relied upon to determine in the evening what the minimum temperature would be on the following morning.

The value to the fruit grower of an accurate forecast of the coming minimum temperature is obviously great, even if it is not given more than six or eight hours in advance. This fact led to a study of the radiation at this station in addition to the other observations during the frost period. It was found that in fair weather such as is favorable for frost and also for uninterrupted radiation the fall in temperature from the time of the maximum during the day to 10 p. m. was very nearly twice as much as it was from 10 p. m. to the time of the minimum on the following morning. For example, if the maximum during the day was 60° and the current temperature at 10 p. m. was 40°, the minimum on the following morning would be 30°. This relation was found to exist without material deviation at any time, particularly during the latter part of March and the early part of April, and seemed to be independent of the atmospheric pressure or of the maximum day temperature. This seems to suggest the possibility of developing a method from study of the radiation by which it will be possible to inform the growers by, say, 8 p. m. or 9 p. m. exactly what the minimum temperature will be on the following morning.

There are now between 3,000 and 4,000 acres of developed orchards in the Lewiston-Clarkston district. The planting of new orchards is going on; some hundreds of acres of orchards will come into bearing next year and the increase will continue at the rate of about 1,000 acres a year until eventually there will be something in excess of 20,000 acres in orchards in the territory contiguous to Lewiston. There will be a marked increase in the practice of orchard heating in the frost season during the next few years, and there will naturally follow a corresponding increase in the importance of the Weather Bureau to the orchardists.

It does not require a close study of the foregoing reports to become aware of the importance of frost forecasts and the complexity of the problem of making them in this part of the country. As before stated, the orchardists want to know just how cold it is going to get

in their orchard and they want this information as far ahead of the time of occurrence as possible. We know that the temperature may vary as much as 8° or 10° in orchards a few miles apart and that it is not considered necessary to protect an orchard during the blooming period unless the minimum temperature goes below 29° .

Each locality has a different environment, and owing to mountain and valley breezes needs special treatment, which is evidently beyond the capability of one man to give to all the places. The plan adopted therefore is to have the district forecast amplified by a trained scientist on the ground. This is the system in operation in handling the daily forecasts of weather and temperature at all important stations of the Weather Bureau, and it is the only way to insure good work in the making and disseminating of frost forecasts in this district.

It will be noticed from the reports of the local men that data from nine new stations, viz, five in the Yakima Valley, two in the Lewiston district, one in the Boise district, and one from Medford, Oreg., were obtained during the spring of 1911 for study purposes. At a few of these stations thermograph traces were also secured. It is now proposed to analyze these data from the forecaster's standpoint to see if it is not possible to arrive at facts which will be helpful in making frost forecasts.

In 1882 Lieut. (now Brig. Gen.) James Allen published a small memoir entitled "To Foretell Frost by the Determination of the Dew Point." It is claimed in this publication that if the dew point is above freezing in the early evening the minimum temperature the next morning will be above freezing, and vice versa if the dew point is below freezing the minimum the next morning will be below that mark. The inference to be drawn from this publication, as well as from others that preceded it, is that it is an easy matter to predict frost when the dew point is known. However, meteorologists¹ since then have generally reached the conclusion that the dew point of the previous evening does not give much, if any, indication regarding the minimum temperature the next morning.

Our investigations, however, rather infer that in some places the dew point is of value in this work, and Mr. O'Gara and Mr. Wells both rely on it to a certain extent in making their local forecasts of frost. Mr. O'Gara as far back as 1908 discovered a relationship between the dew point of the previous evening and the minimum temperature the next morning, and in the *Monthly Weather Review* for September, 1910, he stated:

There is a relation existing between the dew-point temperature observed in the early evening and the minimum temperature of the following morning. For the Rogue River Valley it has been found that when the atmospheric tempera-

¹ Moore's Descriptive Meteorology, p. 114.

ture in the early evening is between 56° and 60° F. the dew-point temperature may be relied upon generally to indicate the minimum morning temperature. It has been found that for such atmospheric temperature, with clear sky and northerly winds, the minimum temperature to be expected is 3° or 4° below the dew-point temperature as observed. If the daily temperatures have been high and the winds are from the west or westerly quarters, the minimum temperature will always be higher than the observed dew point. Again, during the latter part of the spring season with long days and a very large amount of insolation the minimum temperature usually remains the same as the dew point, or even higher, depending upon the maximum temperature during the day.

An accurate record was kept during the spring of 1911 of the dew point at Boise, North Yakima, and Medford. These dew-point observations were taken on the ground with a sling psychrometer of standard make, the first observation at about 4.30 p. m., Pacific time, and it was followed by others at irregular hours, except no second observation was taken on a few nights when the conditions were markedly unfavorable for the formation of frost. For the month of April the averages were as given in Table II.

TABLE II.—*Dew point and minimum temperature readings, month of April 1911.*

Stations.	Dew point, 4.30 p. m.	Morning minimum temper- ature.	Difference.
Medford.....	34.7	34.8	+ 0.1
North Yakima.....	22.7	36.8	+14.1
Boise.....	26.7	33.5	+ 6.8

In Table II we see the average dew point at about 4.30 p. m. and the average minimum temperature on the following morning agree very closely at Medford, while at North Yakima and Boise there are marked differences. If the differences were constant the problem of predicting exact minimum temperatures would be an easy matter, but instead there are decided variations from day to day. At Medford the range was from +12 to -8, at North Yakima from +30 to -8, and at Boise from +18 to -6. These differences were obtained from the records for the entire month, during which time all sorts of weather prevailed. If we only take dew-point observations that are followed by freezing temperatures we cut these ranges down considerably at Medford and North Yakima, but no change is effected at Boise. The reduction is from the positive side in all cases, as the negative side remains the same. The ranges with this elimination are still too great to be helpful in judging what the minimum temperature will be unless they can be still further reduced through correlations with different phases of weather, and an attempt has been made to do this with the following results:

TABLE III.—Record of observations at Medford, Oreg., from Apr. 1, 1910, to Apr. 30, 1910, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
1	6.45 p. m.			52.0	45.0	37	Cloudy.	nw.	Brisk.	38	Cloudy at 3 a. m. Firing general.
2	1.15 a. m.			59.0	49.0	39	Clear.	nw.	High.		
2	7 p. m.			47.0	40.0	31	Cloudy.	w.	Brisk.		
3	10 p. m.			41.0	36.5	30	Clear.	w.	Light.	28	
3	6.30 p. m.			55.0	43.0	27	do.	nw.	Slight.		Firing general on valley floor.
3	8.....			47.0	40.0	31	do.	s.	do.		Unsnudged orchards badly hurt.
3	10.....			44.0	38.0	30	do.	se.	do.	27	
3	10.30.....			43.0	38.0	31	do.				
4	6.30.....			65.0	53.0	42	do.				
4	8.15.....			56.0	48.5	41	do.				
5	6.45.....			62.0	49.5	37	Cloudy.	s.	Slight.	39	
5	11.15.....			52.0	47.0	42	do.	n.	Brisk.		
6	6.30.....			59.0	45.0	27	Hazy.	n.	Light.	34	
6	7.20.....			55.0	44.0	31	do.	nw.	Brisk.		
6	9.....			51.0	42.0	31	Clear.	nw.	do.		Clouded again about 3 a. m., Apr. 7
6	7.35.....			59.0	47.0	33	Partly cloudy.	ne.	Slight.	31	Only 1° of frost. No firing.
7	10.30.....			57.5	45.0	30	do.	nw.	do.	31	
8	6.45.....			59.0	48.0	36	Cloudy.	nw.	do.	32	
9	6.45.....			51.0	51.0	44	do.	ne.	Slight.	44	
10	6.35.....			56.0	46.5	36	Partly cloudy.	se.	Strong.		
10	9.45.....			54.0	45.0	35	Clear.	se.	Brisk.	32	Thermometer just reached 32°. No frost.
11	6.45.....			57.0	49.0	41	Partly cloudy.	nw.	Light.	40	
12	6.40.....			59.0	50.0	41	do.	ne.	Slight.		
12	7.45.....			56.0	49.0	40	Clearing.	ne.	do.	40	
13	6.40.....			52.0	42.0	29	Clear.	e.	Brisk.	26	Firing general. Some orchard temperatures raised 10°.
13	11.45.....			41.0	36.5	30	do.		Slight.		
14	6.30.....			64.0	48.0	29	Partly hazy.				No firing done.
14	11.30.....			45.0	39.5	32	Clear.	s.	Slight.	31	
15	6.45.....			70.0	52.5	34	do.	w.	do.	31	
15	11.....			53.0	44.5	34	do.	s.	Brisk.		
16	6.40.....			71.0	56.0	43	Hazy.			40	
17	6.45.....			76.0	57.0	41	do.			38	
18	6.45.....			74.0	58.0	46	do.			42	
19	6.45.....			51.0	49.0	47	Raining.	n.	Light.	49	
20	6.40.....			61.0	51.0	43	Clear.	w.	Slight.		
20	10.30.....			49.0	46.0	40	do.	se.	do.	39	
21	6.45.....			69.0	55.0	43	Hazy.	sw.	do.	37	
22	6.50.....			74.0	59.0	48	Clear.	sw.	do.	45	
23	6.45.....			79.0	57.0	37	do.	s.	do.	40	

24	6.45	80.0	60.0	45	Few clouds.	nw.	do.	44
25	6.30	58.0	49.5	42	Hazy	nw.	High.	44
26	6.45	58.0	47.0	35	do	ne.	Strong	44
27	10.15	46.0	41.0	35	Clear	ne.	do	33
28	6.40	59.5	49.5	40	Raining	ne.	Strong	40
29	6.45	60.0	46.0	29	Clear	ne.	Light.	40
30	6.45	45.0	40.0	34	do	ne.	do	36
31	6.45	48.0	47.0	46	Raining	w.	Slight	45
32	5.35	56.0	47.5	39	Partly cloudy	nw.	Brisk	45
33	6.30	54.5	47.5	40	do	nw.	do	45
34	6.30	54.5	47.5	40	do	nw.	do	45
35	8.45	50.0	46.5	43	Raining	ne.	Slight.	37

TABLE IV.—Record of observations at Medford, Oreg., from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.		Direction.	Force (estimated).		
1	5	28.00	-0.05	72.5	51.5	Clear	nw.	Brisk		Slight hoar frost on ground. Clouded between 4 a. m. and 6 a. m. Lowest temperature recorded, 30°. No firing; no damage.
1	6.30	28.00	—	66.0	46.0	do.	nw.	Gentle	34.0	
2	5	27.90	+ .05	63.0	50.0	Cloudy	ne.	do.	35.0	
2	6.30	27.90	—	57.0	45.0	do.	ne.	do.		
3	5	28.00	—	53.0	44.5	do.	ne.	Brisk		
3	6.30	28.02	—	52.0	44.0	do.	ne.	do.		
4	5	28.00	—	41.0	39.0	Raining	nw.	Gentle	37.0	Rain began about 3 a. m.
4	6.30	28.00	—	40.5	30.0	do.	nw.	do.		
5	5	28.00	—	53.0	48.0	Cloudy	nw.	do.	35.0	
5	6.30	28.00	—	51.0	46.0	do.	nw.	do.		
5	8.30	28.05	+ .05	44.0	42.0	Partly cloudy	n.	do.	39.5	
6	5	28.15	—	60.0	49.0	do.	n.	Very gentle		
6	6.30	28.15	—	54.0	46.0	Clear	nw.	Gentle	30.0	Light frost. Temperature ranged from 29° to 31° over valley. Unfired tracts not injured.
7	5	29.74	— .05	67.0	53.0	do.	nw.	do.		
7	6.30	29.74	—	60.0	52.0	do.	nw.	do.		Wind blew briskly from all quarters after 8 p. m., but principally from south and southeast.
7	8.45	29.74	—	53.0	48.0	do.	nw.	Brisk	35.0	At 9 p. m. sky cleared and temperature fell rapidly. Had the sky remained clear freezing temperatures would have occurred.
8	5	29.49	— .01	58.0	48.0	Cloudy	n.	Gentle		Clouded in early morning.
8	6.30	29.54	+ .05	55.0	47.0	do.	sw.	Brisk		
8	8.45	29.54	+ .05	49.0	44.0	Clearing	sw.	Gentle	36.0	
9	5	29.69	+ .05	51.0	40.0	Partly cloudy	w.	Brisk		
9	6.30	29.74	+ .05	45.0	41.0	do.	w.	do.		
9	9.45	29.79	+ .05	42.0	39.0	do.	w.	do.	36.0	
10	5	29.79	—	41.0	38.0	Rain	nw.	Gentle	31.5	Clouds, rain, snow.
10	5	29.94	—	41.0	37.0	Partly cloudy	nw.	Brisk		Clouds prevailed most of night. Lowest temperature, 24°. Fired in few spots where temperature below 29° occurred.
11	6.30	30.24	+ .05	34.5	39.0	do.	w.	do.	29.5	Clouds prevailed till 4.30 a. m. Sky cleared and temperature went to 27° in greater part of valley. Lowest recorded, 25°.
12	5	28.40	—	40.5	37.0	do.	ne.	do.		
12	6.30	28.40	—	37.5	35.5	Raining	ne.	Gentle	27.5	Wind strong from southerly and westerly quarters till 5 a. m.
13	5	28.45	—	54.0	41.5	Clear	n.	do.		Changed, and sudden drop of temperature. Lowest recorded, 22°. General, 23° to 25°.
13	6.30	28.45	—	50.5	39.0	do.	se.	Brisk	25.0	Wind strong from south all day. Changed to north after 8.30 p. m.
14	5	28.40	— .05	66.0	47.5	do.	se.	do.		Reached 32° at 2 a. m. Temperature reported, 22-25° over valley.
14	6.30	28.40	—	61.0	45.0	do.	se.	Gentle		Unsmudged tracts badly damaged.
14	Midnight	28.45	—	38.0	34.0	do.	nw.	do.	25.0	

15	5	.....	28.30	.....	70.0	52.0	33.0	.....do	nw.	Brisk	.....	Remained clouded all night, with northerly winds.
15	6.30	.....	28.30	.....	64.0	48.0	29.0	Partly cloudy	nw.	Gentle	.....
15	8	.....	28.35	.....	55.0	46.0	36.0	.....do	nw.	.....	41.0	
16	Noon	.....	28.35	+ .05	62.0	51.0	40.0	Clear	nw.	Brisk	.....
16	5	.....	28.30	.....	64.0	51.0	38.0	.....do	nw.	.....	.....	Temperature of 30° over valley, generally over valley. Firing not necessary.
16	6.30	.....	28.30	.....	68.0	47.0	35.0	.....do	nw.	Gentle	.....
16	10	.....	28.32	+ .02	43.5	39.5	35.0	.....do	nw.	Very gentle	30.0	
17	5	.....	28.15	- .05	71.0	51.0	28.0	Partly cloudy	ne.	.....do	.....	Clouds all night.
17	6.30	.....	28.15	- .05	62.5	49.5	35.5	Cloudy	.....	.....	.....
17	9.30	.....	28.10	.....	58.0	47.0	35.0	.....do	.....	.....	40.0	Mostly clouded over key station at Medford. Temperatures of 24° to 26° recorded in north end of valley. Few fires. Upper end of valley remained clouded most of night.
18	5	.....	28.40	+ .05	52.0	43.0	32.0	Partly cloudy	nw.	Brisk	.....
18	6.30	.....	28.45	+ .05	48.0	39.0	26.0	Clearing	n.	.....do	23.5	
19	5	.....	28.30	- .05	60.0	48.0	35.0	Clear	nw.	Gentle	.....
19	6.30	.....	28.30	.....	55.0	45.0	33.0	.....do	nw.	.....do	29.5	
20	5	.....	28.00	- .05	73.0	56.0	41.0	.....do	nw.	.....do	.....	Some firing.
20	6.30	.....	28.00	.....	67.0	53.0	40.0	.....do	.....	.....	37.5	Partly cloudy during morning.
21	5	.....	28.14	.....	70.0	54.5	38.0	.....do	ne.	Brisk	.....
21	6.30	.....	28.15	+ .04	64.0	52.0	41.0	.....do	n.	.....do	35.0	
22	5	.....	28.17	.....	72.0	53.5	35.0	.....do	ne.	Gentle	.....
22	6.30	.....	28.17	.....	66.0	53.0	41.0	.....do	ne.	.....do	37.0	
23	5	.....	28.10	.....	81.0	58.0	38.0	.....do	nw.	.....do	.....
23	6.30	.....	28.10	.....	73.0	56.0	41.0	.....do	.....	.....	40.5	
24	5	.....	27.95	- .05	80.0	60.0	44.0	Hazy	nw.	Brisk	.....	Cloudy most of night.
24	6.30	.....	28.00	+ .05	71.0	52.5	33.0	Partly cloudy	nw.	.....do	39.0	
25	5	.....	27.90	- .05	64.0	53.0	44.0	Cloudy	nw.	.....do	.....	Do.
25	6.30	.....	27.90	.....	57.0	48.5	44.0	.....do	nw.	.....do	43.5	
26	5	.....	27.85	.....	50.0	45.0	40.0	.....do	ne.	Gentle	.....	Do.
26	6.30	.....	27.85	.....	50.0	45.0	40.0	.....do	ne.	.....do	39.5	
27	5	.....	28.11	- .01	52.0	43.5	33.0	Partly cloudy	n.	Brisk	.....	Do.
27	6.30	.....	28.15	+ .05	49.5	41.0	29.0	.....do	ne.	.....do	38.5	22° in two places for a short time. Average over valley, 26°. Firing general.
28	5	.....	28.25	.....	60.0	46.5	30.0	Clear	ne.	.....do	.....
28	6.30	.....	28.25	.....	54.5	44.0	31.0	.....do	ne.	.....do	27.5	Clouds came about 1 a. m. Remained clouded until early morning.
29	5	.....	28.21	.....	68.5	51.0	32.0	.....do	ne.	.....do	.....
29	6.30	.....	28.25	+ .04	64.0	49.0	32.0	.....do	nw.	Gentle	.....	Cloudy all night with trace of rain.
30	5	.....	28.05	.....	65.0	53.0	41.0	Raining	nw.	.....do	36.0	
30	6.30	.....	28.05	.....	62.0	52.0	43.0	Partly cloudy	nw.	.....do	44.0	

At Medford (see Tables III and IV) the conclusions reached after a careful analysis of the observations taken in April, 1910 and 1911, are as follows: The 5 p. m. dew-point observations show nearly as close an agreement with the minimum temperatures as do the dew-point readings obtained later in the day. The dew point more nearly agrees with the minimum temperature the next morning when the weather is cloudy at the time of the observation, and it is farthest from the minimum temperature when the weather is partly cloudy. Both the average difference and the range are least with cloudy weather and greatest with partly cloudy weather.

The winds are nearly always from the northeast or northwest on evenings with freezing temperatures, and they are usually from one or the other of these directions when no freezing temperatures occur. There is apparently just as wide a variation between the dew point and the minimum temperature when the winds are calm as there is when they are light, gentle, or brisk. On frosty nights the difference between the evening dew point and the minimum temperature the next morning is greatest when the pressure gradients are medium or steep and least when they are weak; when weak, frost seldom occurs. Frosts form oftenest when the barometer at Marshfield is about 30.3 inches (sea level) or above; on one occasion frost formed when the barometer at Marshfield the preceding evening was as low as 29.6 inches. It makes little difference regarding the height of the barometer as to the difference between the dew point and the minimum temperature, although the tendency is for a greater difference the higher the barometer reads.

The position of the highs and lows furnishes the best information in connection with the relationship of the evening dew point with the minimum temperature the next morning. When the high is in the northwest and the low in the southeast, the difference will be greatest and average 5.6° below the dew point; when the low is in the east and the high in the west, the difference will average -3.3° ; when the low is in the northeast and the high in the southwest (moving up the coast), the difference will average -2.4° ; when the high is inland and the low off the California coast, the difference will average $+1^{\circ}$, and when the high is in the north and the low in the south, the average will also be $+1^{\circ}$.

The application of the foregoing factors will approximate the minimum temperatures within 1° in all cases, except when the high is in the northwest and the low in the southeast, and then the approximation will be within $2\frac{1}{2}^{\circ}$, which is sufficiently close to be of value in determining the question of "how cold it will be." More observations will probably enable us to make other correlations that will be helpful, and it is probable that we will find some "freaks"

as our record lengthens that will need further study to properly classify.

During the two seasons there were nine cases with the dew point above 32 that were followed by freezing temperatures. In none of these cases was the minimum temperature low enough to make it necessary to start fires in the orchards, the lowest being 29.5° on April 19, 1911. The temperatures that occurred were what would be expected by using the factors for position of the highs and lows, and they were really "near cases" that are easily handled.

In 6 cases frost did not occur when the evening dew point was below 32, and these cases are puzzling. Cloudiness which prevented radiation was the cause of the absence of frost with these low dew points, but no hard and fast rule can be found to assist in predicting whether or not cloudiness will or will not prevail during the night. If the barometer is low, that alone favors cloudiness, and if high and the surrounding country is cloudy and movement sluggish, as indicated by the behavior of the barometer at stations in the vicinity, clouds will probably continue.

TABLE V.—Record of observations at North Yakima, Wash., from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change hours.	Dry.	Wet.			Direction.	Force (estimated).		
1	4.10	28.53	+0.03	63.0	44.5	18	.....	ne.	10	.....	Strong southwest to west wind all day.
1	6.40	28.60	+0.06	49.0	39.0	25	.....	ne.	8	.....	Wind in puffs during evening.
1	8.50	28.67	+0.06	46.0	37.0	24	.....	n.	Light	35	Wind in puffs.
1	10	28.70	+0.03	44.8	36.3	24	.....	n.	do	.....	Very light wind; almost none.
2	4.15	28.66	-0.08	53.7	39.0	17	10 a. st.	c.	do	.....	Clouds thinned out till sky was almost clear between 7.30 and 8.30 p. m. At 9 they were still quite thin.
2	6.45	28.64	-0.01	48.2	36.2	15	.....do.	ne.	do	.....
2	9	28.65	+0.01	45.8	35.1	17	.....do.	ne.	do	37	Cloudy all day.
3	4.20	28.54	(-)	50.0	41.0	29	.....	n.	6	.....	Sky was clear all night up to about 2 or 3 a. m.; after that it clouded over and prevented a freeze which would otherwise have occurred.
3	6.40	28.55	(+)	44.2	38.7	31	9 a. st.; few s. cu.	n.	Light	.....
3	8.50	28.56	+0.01	41.8	37.3	32	Few cl. st.	n.	do	.....
3	11	28.56	.....	38.5	35.0	30	Few a. st.	n.	do	34	
4	4.20	28.64	(-)	48.5	42.5	36	3 st. cu.	n.	6	.....
4	6.50	28.63	+0.01	45.0	36.3	23	4 st. cu.	n.	6	.....	Wind in light puffs from north.
4	9.10	28.66	+0.01	40.0	33.2	22	.....	n.	Light	28	Clear all day and light southeast air.
4	9.10	28.67	(-)	52.0	38.2	15	Few cl. st.	se.	do	.....	Few cl. moving at tremendous speed from northwest.
5	4.20	28.65	(-)	47.4	36.0	19	Few cl.	s.	do	.....	Surface drift of air faintly discernible from south. Halo at 9 p. m.; cl. and ci. st. moving swiftly from northwest.
5	6.50	28.66	(-)	44.0	33.8	17	4 cl.	s.	do	.....	Cl. st. clouds moving from northwest. Cleared off at 11.30 and stayed clear all night.
5	9.20	28.70	+0.03	44.0	33.8	17	.....	.....	.....	25	
5	11	28.69	-0.01	37.5	.....	.....	7 cl. st.	.....	.....	.....
6	4.20	28.80	+0.06	57.5	43.0	23	.....	n.	6	.....	Brisk north wind during day.
6	6.55	28.83	+0.04	48.8	38.2	22	.....	n.	8	.....	Bank of st. cu. clouds low in northwest.
6	8.50	28.87	+0.04	46.2	37.2	24	.....	n.	5	.....	Wind blew about 4 to 6 miles per hour through night, sufficiently to almost jeopardize the forecast.
6	11	28.90	+0.03	43.0	.....	.....	.....	n.	5	30	Scarcely any motion to air.
7	4.20	28.86	-0.04	61.0	45.0	24	.....	s.	Light	.....	Calm and clear all night.
7	6.50	28.84	-0.01	54.8	41.3	23	.....	sw.	do	.....
7	9	28.60	.....	46.8	36.8	22	.....	.....	.....	30	
8	4.20	28.44	-0.08	69.0	49.0	25	3 cl.; 2 ei. st.; 2 cu.	se.	Light	.....
8	6.50	28.40	.....	62.7	48.0	33	10 st. cu.	w.	do	45	
9	4.20	28.47	-0.02	55.0	44.5	32	2 cl. st.; 8 st. cu.	sw.	16	.....	Clear and calm for a large part of night. Sky became overcast by morning, preventing a freeze.
9	7	28.51	+0.03	50.0	43.0	35	4 a. cu.; 3 st. cu.	sw.	10	.....
9	9	28.57	+0.06	46.0	40.5	33	4 st. cu.	.....	.....	39	Cloudy all day with trace of rain in afternoon.
10	4.20	28.60	-0.02	46.8	38.8	29	10 cu.	s.	6	.....
10	6.50	28.60	+0.02	43.0	33.3	16	3 cu.	sw.	8	.....	Southwest wind 3 to 6 miles blew all night. Some cloudiness.
10	9	28.65	+0.05	37.0	31.0	21	Few cu.	sw.	6	29	0.01 inch of snow in afternoon.
11	4.20	28.73	+0.01	47.0	35.8	17	5 cu.; 5 st. cu.	nw.	10	.....	Northwest wind greater part of night and occasional cloudiness.
11	7	28.75	(+)	41.0	32.0	16	7 st. cu.	nw.	10	26	

12	4.20	28.95	(+)	45.0	33.0	8	7 cl.	nw.	s.	Cloudy all day and fresh north wind.
12	7	28.98	+ .03	40.0	30.3	10	Few cl.	nw.	5	
12	9.45	29.05	+ .05	36.7	30.2	19		nw.	6	
13	20.05	29.16	(+)	34.6	38.6	10		s.	3	Clear all day with gentle south to southeast w.m. l.
13	7	29.20	+ .04	37.0	37.0	22		nw.	6	
13	4.20	29.25	+ .02	59.0	42.4	18		sw.	Light	Clear all day.
14	7	29.30	+ .01	53.5	33.0	15	Few cl. st.	se.	do	
14	9.30	29.35	+ .01	42.7	33.0	16				
15	4.20	28.95	+ .08	68.0	46.2	14	Few cl.; 1 cl. st.; 3 a. st.	s.	Light	Clear nearly all day, cloudiness commencing about mid-afternoon.
15	7	28.90	- .04	59.0	43.3	21	10 a. st.	s.	do	
15	9.30	28.90	(+)	55.4	41.8	21	Overcast.	s.	do	
16	4.20	28.95		59.0	43.3	21		nw.	10	
16	7	28.97	+ .02	49.6	39.6	21	Few cl. st.; few cl.	nw.	8	
16	9.30	29.01	+ .02	45.7	36.5	23		nw.	8	
17	4.20	28.81	- .07	60.8	44.3	22	10 a. st.	sw.	5	Sky overcast major part of day; about 25 per cent of sunshine.
17	7	28.82	- .04	56.3	42.3	23	do	s.	Light	
18	4.20	28.92	+ .05	53.0	40.5	23	Few cl.	nw.	14	Wind during night prevented freeze.
18	7	28.98	+ .03	43.3	37.0	28	Few st. cl.	nw.	10	
18	9	29.05	+ .02	42.5	36.8	29		nw.	20	
19	4.20	29.03	+ .02	64.0	46.7	23	3 cl. st.	ne.	6	Shortly after 7 p. m. the wind increased to about 10 or 12 miles per hour, subsiding shortly after 8 o'clock. Increased after 9.30 p. m. and blew at intervals through night.
19	7	29.10	+ .01	51.7	43.0	28	do	nw.	6	
19	9	29.13	+ .03	50.0	40.5	28		nw.	Light	
19	10.45	29.10	- .03	48.3	39.5	28		nw.	Light	
20	4.20	28.70	- .07	72.0	51.5	29		nw.		
20	7	28.71	+ .04	65.3	49.0	31		n.	Light	Very little motion to air.
21	9	28.73	+ .02	56.0	44.4	31	7 st. cl.	ne.	8	
21	4.20	28.75	+ .05	71.0	53.2	36		nw.	8	
21	7	28.82	+ .05	59.4	47.9	36		nw.	6	
21	10.45	28.88	+ .01	52.0	44.2	35		nw.	44	
22	4.20	28.93	- .01	68.0	49.7	23	Few cl.	ne.	Light	
22	7	28.95	+ .02	64.0	48.7	32	do	ne.	do	
22	9.25	28.98	+ .02	57.0	45.8	33		nw.	do	
23	4.20	28.88	- .04	74.7	53.8	33		s.	6	Do.
23	7	28.85	- .02	67.3	51.2	35				Do.
23	9.15	28.85	+ .01	56.8	45.8	34		sw.		Wind in puffs; scarcely any at times.
23	4.20	28.57	- .05	81.0	55.3	29	Few cl.; few cl.	w.	6	
24	7	28.58	+ .03	70.7	53.2	35	few cl.		Light	
24	9	28.60	+ .02	62.8	50.0	37		nw.	6	
25	4.20	28.65	- .03	60.0	43.8	21	4 cl. st.	nw.	10	
25	7	28.65		52.0	39.7	20	3 cl. st.	nw.	10	
25	9	28.68	+ .03	49.0	37.2	18		nw.	5	
25	11	28.67	- .01	46.1	36.2	18		nw.	Light	
26	4.20	28.44	- .04	63.8	44.3	14	3 cl. st.	sw.	do	Very little motion to air.
26	7	28.44	+ .01	60.8	44.2	21	4 a. st.	nw.	do	
26	10.45	28.59	+ .05	51.8	41.0	27		nw.	do	
27	4.20	28.63	+ .03	63.0	46.8	25	Few cl.; few cl. st.	nw.	18	Wind commenced about 3 p. m. Calm at Sunnyside at 4.30 p. m.
27	7	28.71	+ .05	53.5	41.3	24	Few cl. st.	nw.	14	
27	8	28.75	+ .04	52.0	40.0	23		nw.	18	

TABLE V.—*Record of observations at North Yalima, Wash., from Apr. 1, 1911, to Apr. 30, 1911, inclusive—Continued.*

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
27	9.30	28.78	+ .03	50.0	49.2	24	.....	nw.	24	41	Barometer rose steadily and wind continued to blow throughout night.
28	4.20	28.88	.....	66.5	46.3	19	7 cu.	n.	8	.....	Wind in puffs.
28	7	28.90	+ .02	60.0	44.0	22	1 cu.	n.	8	.....	Wind a little steadier.
28	9	28.96	+ .06	54.0	42.2	27	.....	n.	Light	.....
28	11	28.98	+ .02	52.5	42.0	28	.....	n.	10	43	Wind in gusts.
29	4.20	28.95	.....	66.8	47.0	21	3 cu.	e.	Light	.....	Wind variable and in puffs. Day averaged about seven-tenths cloudy. Cumulous clouds commonest.
29	7	28.95	.....	63.0	46.3	25	2 cu.	e.	do	.....
29	9.15	28.95	(+)	53.5	42.5	28	.....	n.	do	39	
30	4.20	28.77	-.04	70.0	48.5	21	3 cu.	sw.	do	.....	Very slight movement to air.
30	7	28.73	-.03	63.5	46.3	24	7 cu.; few a. st.	sw.	do	.....	Do.
30	10	28.74	+ .01	53.3	42.0	27	.....	nw.	do	41	

Frost seldom forms at North Yakima (see Table V), as the dew-point is usually far below the freezing point. The dew-point observations taken at 7 p. m. show a closer relationship to the minimum temperature the next morning than do those taken at 4.20 p. m. For the month of April the differences averaged 14.6 at 4.20 p. m. and 12.2 at 7 p. m. For mornings followed by freezing temperatures these differences were 9 at both the 4.20 p. m. and the 7 p. m. observations. The ranges are large, being for the month from -8 to $+30$ at 4.20 p. m., and from $+3$ to $+23$ at 7 p. m. On mornings followed by freezing temperatures they were from -8 to $+16$ at 4.20 p. m. and from $+3$ to $+14$ at 7 p. m. There is a strong probability that the dew-point observation taken at 4.20 p. m. on the 4th is in error, as it is the only date during the series when the following temperature sank below the dew-point, and the observation taken at 7 p. m. on that date gave a dew-point 13 points lower, thus making the minimum temperature 5° higher instead of 8° lower, as computed from the 4.20 p. m. observational data. If we exclude this apparently erroneous reading, we get a range on frosty mornings from the 4.20 p. m. observation from 0 to $+16$, which, as will be seen, is 5° greater than that obtained from the observations taken at 7 p. m.

It seems to make no difference at North Yakima whether the weather is clear or cloudy when the dew-point observation is taken as to the variations in the range between that point and the minimum temperature the next morning. When clear the average difference for 18 observations was 13.3, and when cloudy for 7 observations it was 12.6. On partly cloudy evenings the average was 19. There were five mornings with freezing temperatures when the winds during the preceding evening were from the southeast or south and four when they were from the north or northwest. There were many other evenings with the same directions that were not followed by freezing temperatures.

The differences between the evening dew point and the following minimum temperature were practically the same, no matter what direction the wind blew from or whether or not the pressure gradients were for light or strong winds. No freezing temperatures followed those evenings when the winds were brisk, but when they were light there were four and when moderate there were five mornings with freezing temperature. The dew point at North Yakima averaged 22.7 at 4.20 p. m. and 24.6 at 7 p. m., but when above 32 at either of these hours no frost need be expected, which is contrary to the conditions in the Rogue River Valley, where there were nine days in two years with the dew-point above 32 that were followed by freezing temperatures. Freezing temperatures occur at all heights of the barometer, beginning with readings as low as 29.80 inches up to 30.50

inches or more. Owing to the uncertainty in the temperature factor used in reducing barometer readings to sea level at the altitude of North Yakima the isobars sometimes appear to be misplaced, and very little weight can be given to the fact of their being crowded together or wide apart when making frost forecasts for this station.

When the high is in the southwest (moving up the coast) and the low in the northeast, the dew-point will be from 0 to 9° lower than the minimum temperature the next morning; when the high is in the west and the low in the east, the dew point will be from 7° to 16° lower; when the high is in the northwest and the low in the southeast, these differences will range from 10° to 15° ; and when the high is in the east and the low in the west the difference was 15° on the only occasion when this situation occurred.

The lowest dew-point at 4.20 p. m. that was followed by freezing temperature was 8, and the lowest at 7 p. m. was 10, while the highest (excluding the apparently erroneous observation on the 4th) were 29 and 23, respectively. These factors show variations too large to be of much value in placing the minimum temperatures at North Yakima, but they are helpful when taken in consideration with other conditions, and it is believed the dew-point observations should be continued at this station as well as at Medford. It is worthy of note that when the gradients were steep at North Yakima and freezing temperatures occurred, the high was in the southwest and the low in the northeast, and radiation played but a small part in cooling the air, but instead genuine freezes occurred with a great deal of cloudiness.

TABLE VI.—Record of observations at Boise, Idaho, from Apr. 1, 1911, to Apr. 30, 1911, inclusive.

Date.	Time of observation.	Barometer.		Psychrometer.		Dew point.	State of weather.	Wind.		Minimum temperature next morning.	Remarks.
		Actual reading.	Change last 2 hours.	Dry.	Wet.			Direction.	Force (estimated).		
1...	5.15.	26.88	—0.05	69.8	46.9	18	Clear.	n.	10	35	Sky clouded during night.
2...	5.15.	26.88	—0.05	58.6	41.0	15	Cloudy.	w.	4		Partly cloudy to cloudy during night.
2...	7...	26.86	—0.04	57.7	41.4	19	do.	w.	2	35	Do.
3...	5.20.	26.84	—0.03	55.8	42.1	25	do.	nw.	5	42	Do.
4...	5.20.	26.97	—0.01	42.4	39.4	36	Light rain.	ne.	3	33	Cloudy all night.
5...	5.20.	26.90	—0.02	48.2	36.5	19	Clear.	nw.	14	26	Clear all night.
6...	5.20.	27.05	—0.02	53.2	42.3	29	do.	nw.	4	28	Do.
7...	5.20.	27.25	—0.01	56.7	40.6	18	do.	sw.	4		Chinook began during night.
7...	7.50.	27.25	—0.01	48.2	37.9	24	do.	e.	2	33	Do.
8...	5.20.	26.99	—0.02	54.2	47.8	34	Light rain.	se.	8	47	Rapidly falling barometer.
9...	5.20.	26.95	—0.01	54.0	43.5	32	do.	w.	8	35	Thunderstorm in afternoon.
10...	5.15.	27.05	—0.05	51.8	40.8	28	Cloudy.	ne.	3	34	Cloudy most of night.
11...	5.20.	27.10	.....	34.5	32.0	28	Light snow.	w.	10	24	Cloudy to midnight; clear to partly cloudy midnight to 2.20 a. m. of 12th; cloudy thereafter.
11...	8...	27.09	.....	33.1	30.9	28	Cloudy.	se.	4	24	Generally cloudy all night, 12th-13th.
12...	5.25.	27.23	—0.04	33.3	30.2	26	do.	n.	12		
12...	8.15.	27.26	—0.02	32.0	29.3	25	do.	n.	2	20	Clear all night.
13...	5.20.	27.45	—0.02	44.1	32.4	11	Clear.	n.	6		Do.
13...	8.15.	27.47	—0.03	38.1	32.7	26	do.	nw.	2		Do.
13...	10...	27.52	—0.05	35.6	29.1	18	do.	n.	3	21	Do.
14...	5.20.	27.61	—0.02	50.9	36.0	10	do.	s.	4		Do.
14...	8...	27.61	.....	46.0	34.5	16	do.	nw.	3	26	Do.
15...	5.20.	27.43	—0.07	60.4	41.5	13	do.	se.	9	31	Do.
16...	5.20.	27.33	—0.05	63.3	45.0	22	do.	nw.	9		
16...	8.20.	27.13	—0.04	53.8	42.1	28	do.	n.	4	28	Do.
17...	5.20.	27.19	—0.04	59.2	42.3	20	do.	w.	9		Chinook conditions in night.
17...	7.45.	27.17	—0.02	51.3	38.8	22	do.	n.	3		
18...	5.20.	27.15	—0.16	35.6	34.7	34	Light snow.	nw.	14	32	Snow and rain during night.
19...	5.20.	27.26	—0.03	51.4	41.7	30	Cloudy.	ne.	6	37	Cloudy all night.
20...	5.20.	27.24	—0.03	45.3	40.6	35	Partly cloudy.	se.	5	30	Clear part of night.
21...	5.20.	27.23	—0.01	55.9	43.2	28	do.	s.	3		
21...	8...	27.23	—0.01	50.7	42.3	33	do.	se.	2	33	Clear all night.
22...	5.15.	27.21	—0.02	66.4	49.6	33	Clear.	nw.	8		Do.
22...	8.15.	27.23	—0.02	57.6	47.7	38	do.	n.	3	37	
23...	5.20.	27.24	—0.02	68.2	51.3	31	do.	ne.	7	40	Chinook conditions during night.
24...	5.20.	27.08	—0.04	71.6	51.1	31	do.	n.	4	49	Generally cloudy all night.
25...	5.15.	26.86	—0.04	61.5	54.3	40	Partly cloudy.	nw.	5	45	Cloudy and rainy all night.
26...	5.15.	26.71	—0.02	65.1	50.0	36	do.	n.	6	41	Cloudy and damp all night.
27...	5.15.	26.97	—0.01	47.3	42.8	38	do.	nw.	6	42	Cloudy all night.
28...	5.15.	27.16	—0.01	50.4	45.9	41	do.	n.	7	36	Partly cloudy to clear during night.
29...	5.15.	27.20	—0.01	59.4	47.5	36	do.	se.	10		
29...	8.20.	27.22	—0.03	52.3	44.6	37	Partly cloudy.	nw.	3	35	Chinook conditions at night.
30...	5.15.	27.16	—0.03	61.3	45.3	27	do.	n.	4		
30...	8...	27.13	—0.01	54.1	44.6	34	Clear.	sw.	2	44	

On account of elevation the danger of frost in the Boise district (see Table VI) extends over a longer period than at either of the other places which have been considered. During the spring of 1911 there were 10 mornings in April with the temperature 32° or lower and 3 in May. The May frosts were not heavy, and that our comparison may cover the same period in all three districts only those for April have been considered in this discussion.

Regular dew-point observations were taken at 4.20 p. m., Pacific time, and quite a number were taken at about 7 p. m., but there were not enough of the latter to definitely determine its advantages as compared with the earlier observation. Mr. Wells, the official in charge of the Boise station, states in his report that "the 8 p. m. (7 p. m. Pacific time) dew-point on the lawn forms an excellent indication of the expected minimum temperature near the ground when taken into consideration together with the relative humidity and other local conditions"; also, "that the 5.20 p. m. (4.20 p. m. Pacific time) reading made before taking the regular observation is too early for best results in the spring." Mr. Wells thinks when the humidity is high the minimum temperature is usually below and when the humidity is low it is above the dew-point of the previous evening. The same rule works with the dew-point; when it is high the minimum temperature is below and when low it is above, and the lower the dew-point the higher above the minimum temperature will be, therefore there is no special object in bringing the humidity into the question when the dew-point answers the same purpose.

The average dew-point at Boise at 4.20 p. m. for the month of April, 1911, was 26.7 and the average minimum temperature the next morning was 33.5° , which is 6.8° higher. As some of the differences were minus, the average of the difference column is greater than 6.8 , being, in fact, 8.5 ; and the range is very great, being from $+18$ to -6 . This shows very plainly that the evening dew-point is of no value in placing the minimum temperature the following morning, unless we can segregate the observations in such a way as to get uniform differences under similar conditions.

When the weather is clear the differences between the 4.20 p. m. dew-point and the following minimum temperature averaged 11.2 , and they ranged from $+18$ to -1 ; when partly cloudy the average was 8 and the range was from $+17$ to -5 ; and when cloudy the average was 6.9 and the range from $+18$ to -6 . Thus we see the average is greatest and the range is least with clear weather and the average is least and the range greatest with cloudy weather. It is not the average but the range that prevents the use of the dew-point in this connection.

As the time of the observation was nearly at the time of the most rapid diurnal fall in pressure, the two-hour pressure changes were

nearly always minus. On the few occasions when they were plus the average difference was 5.4 and the range from +10 to -6. On only one occasion was the weather clear, with a two-hour plus change in pressure, and then the minimum the next morning was 10° higher than the dew-point the previous evening. If we exclude this instance, the range will be from -6 to +3, and, as a rule, we should look for a minimum temperature about 3° or 4° lower than the dew-point the previous evening.

During the 10 mornings when the minimum temperature was 32° or lower, 6 were during clear weather, 1 with partly cloudy weather, and 3 with cloudy weather. On the clear nights the difference ranged from +18 to -1, on the partly cloudy night the difference was -5, and on the 3 cloudy nights the range was from -2 to -6. There were 8 mornings when the minimum temperature was lower than the previous dew-point, and on 5 of them freezing temperatures occurred, and on 3 mornings the temperature was above 32°, the warmest being 36°.

The highest current temperature followed by frost was 63°, the night being clear and very favorable for radiation. Two freezing temperatures occurred when the winds were light, four with winds from 5 to 10 miles an hour, and three with winds over 10 miles an hour, which shows there is apparently no connection between dew-points, freezing temperatures, and wind velocities, as the variations were as marked with light winds as with those that were stronger. Freezing temperatures occurred twice with north winds, four times with northwest winds, twice with southeast winds, and once with a south wind, and the variations were as marked with one direction as with another. If we consider the bearing the height of the barometer has on the agreement between the evening dew-point and the following minimum temperature, nothing conclusive is to be obtained. Freezing temperatures occurred once with a barometer as low as 29.80 inches, once 29.90 inches, three times 30 inches, twice 30.20 inches, once 30.30 inches, once 30.40 inches, and once 30.50 inches.

Regarding the position of the highs and lows, there were six cases with the high in the northwest and the low in the southeast, and the differences between the dew point and the following minimum temperature ranged from +10 to -4, with an average difference of +2.6. There was only one case for the other positions of the highs and lows, and no conclusions can be drawn from them. The principal freezing temperatures of the month occurred during the passage of a slow-moving high-pressure area from the north California coast to Cape Flattery and thence southeastward to the Great Salt Lake Basin. During the first two days the weather was cloudy and windy; then it became clear, and radiation was excellent.

From the foregoing analysis of the relationship between the evening dew point and the following minimum temperature we arrive at the following conclusions:

First. Dew-point observations taken from two to four hours later than the time of taking the regular evening observation agree more closely with the following minimum temperature than do those taken at the regular hour.

Second. The average difference and the range of the differences between the dew point and the following minimum temperature are greatest with clear or partly cloudy weather and least with cloudy weather.

Third. No inferences can be drawn from wind direction, wind velocity, steepness of barometric gradients, relative height of the barometer, and two-hour pressure changes as to the difference between the evening dew-point and the following minimum temperature.

Fourth. The position of the highs and lows gives important information at Medford regarding the differences between the evening dew-point and the following minimum temperature, and knowledge of this character is of some value at North Yakima, but of little use for the Boise district.

The investigation of the relationship of the evening dew point with the following minimum temperature, besides bringing out the preceding conclusions, also developed the fact that at North Yakima no freezing temperatures occurred when the wind backed a point or two after the 4.20 p. m. observation. Three freezing temperatures occurred when the wind veered a point, five when it remained steady, and one when it shifted from the south to the northwest. Also no damaging temperatures occurred at any place when the preceding maximum temperature was above 68°. At North Yakima the highest maximum temperature followed by a freezing temperature was 64°, and the highest current temperature was 61°; at Boise the highest maximum was 65° and the highest current was 63°; at Medford the highest maximum and the highest current were both 68°; and at Lewiston the highest maximum was 63° and the highest current 52°.

Mr. Thomas states in his report that "it was found that in fair weather, such as is favorable for frost, and also for uninterrupted radiation, the fall in temperature from the time of the maximum during the day to 10 p. m. was very nearly twice as much as it was from 10 p. m. to the time of the minimum the next morning."

To follow up this clue six nights at Medford, four at North Yakima, five at Lewiston, five at Clarkson, and four at Meridian have been selected as those best representing the conditions specified, viz, clear nights with good radiation weather. followed by minimum

temperatures of 32° or lower, and computations have been made to ascertain what the minimum temperature would be the next morning.

The average difference between the computed minimum temperature and the actual minimum temperature on these nights was 3.7° , and the absolute range was from 12° too high to 6° too low. There were 5 cases when the computed minimum temperature exactly agreed with the actual minimum temperature, and out of the total number of 24 cases there were 14, or a little over half, that did not vary more than 3° . This information, therefore, is of value to the local forecaster, but too much dependence should not be placed upon it, as the liability of error is great and the chances are that the estimated minimum temperature will be placed too high, which is a grievous fault.

At Lewiston and Clarkston there were three cases when the computed minimum temperature agreed with the actual minimum temperature, while in all the other cases the computed minimum temperature was too high. At Medford, on the other hand, there was one agreement and three cases when the computed minimum temperature was too low and only two cases when it was too high. It is possible that some of the dates selected did not entirely fulfill the conditions, but conditions are seldom perfect and frost must be predicted, when seemingly the winds are too strong and when there is more or less cloudiness to check radiation.

Another rule that can be followed by the local forecaster is to ascertain the median point between the maximum and minimum temperatures, find the average time it occurs, then take an observation of the temperature at that time, subtract the reading obtained from the maximum temperature, and the remainder will be the approximate fall that will occur to reach the minimum.

Computations after this plan have been made for the same dates as those used in testing the plan offered by Mr. Thomas. On account of the time error not having been noted on the thermograph sheets from some of the stations the exact median point can not be definitely located, but it is not far from 8.30 p. m. By considering 8.30 p. m. the halfway point between the maximum and the minimum temperature, we can arrive at a closer approximation to the minimum temperature than we can by waiting until 10 p. m. and considering that the temperature has fallen two-thirds of the range between the maximum and minimum temperatures. This method of arriving at an approximation offers the further advantage of giving the forecaster earlier information, which of itself is greatly to be desired.

The average differences under this plan are 2.9° as compared with 3.7° by the plan of Mr. Thomas. The variations are from $+6$ to -8 , and there are 3 agreements and 16 cases where the computed mini-

mun temperature was too low and only 7 where it was too high. This is also an advantage, as it is better to make a mistake on the safe side than to predict that it will be warmer than what actually happens. At North Yakima and Meridian the agreements were remarkably close, and in no instance was the difference greater than 4° . At Lewiston, Medford, and Clarkston the agreements were not so close, but they were closer than were the computations based on the 10 p. m. formula.

Mr. Wells reports that a rather unsatisfactory investigation, made by Mr. C. A. Donnel, leads to the belief that "freely exposed thermometers read from 2° to 3° below the true air temperature." Professor Cox arrived at the same conclusion in his investigations in the cranberry marshes at Mather, Wis. He states:¹ The mean depression of the outside thermometers below those in the shelters at the six stations on the bog for the entire season of 1907 was 3° ." Investigations made by Prof. Willis I. Milham at Williamstown, Mass., on 36 cold and cloudless nights showed the temperature averaged 3.9° lower in the open than in a shelter. It is probable that on frosty nights the difference between the true air temperature and the temperature indicated by thermometers hung on trees in orchards is not less than 3° and may average as much as 4° , with variations as great as 6° or 7° , depending upon the radiating qualities of the air, the density of vegetation, and the character of the soil.

The thermometers hung on trees, while not indicating the true air temperature, indicate, roughly, the temperature of the trees themselves, which is the temperature the orchardist is interested in, but it is not the temperature the forecaster can predict, because it varies so greatly in different orchards, and even in different parts of the same orchard.

The accepted standard for true air temperature is obtained by exposing a thermometer in a louvered shelter in an open place where the air can move freely through it. The shelter will keep the instruments dry and screen off the direct and reflected sunshine, which otherwise would affect the reading of the instruments. Instruments so exposed will read nearly alike if they are elevated a few feet above the ground and the territory covered is not too large and has the same physical characteristics. These are the temperatures that to a certain extent control the variations due to radiation from the vegetation and soil, and they are the temperatures that the forecaster endeavors to predict. The variations should be ascertained by the individual orchardist for himself. This can approximately be done by comparing the readings made in the orchard with those made in the louvered shelter.

¹ See p. 27, Weather Bureau Bulletin T.

Professor Cox¹ found that the temperature on cold nights varied a few rods apart as much as 6° or 8° in the cranberry marshes at Mather, Wis. It is probable we would not get quite so great differences in the orchards as he did in the cranberry marshes, but it would be considerable, and under similar conditions the same or very nearly the same every night. When an orchardist knows how the temperatures vary in his orchard and how these temperatures compare with those obtained in a louvered shelter in the neighborhood, it is an easy matter for him, with the help of the forecasts, to calculate just how cold it will be at his place whenever frost is predicted.

The responsibility for accurate forecasts should rest on the district forecaster for the prime "key" stations, upon the local forecaster for the secondary "key" stations and for the individual orchards as far as practicable, and upon the orchardist for his own immediate locality when the local forecaster can not handle that particular section for him.

The main reliance of the district forecaster is on his weather charts, which should be classified into types and studied from that point of view. Even with their help it is not always possible to prevent errors, as we all know how business men sometimes make mistakes in their accounts, which are based upon certainties, and we should not expect perfection in work that to some extent is based on uncertainties.

We have in this district damaging temperatures, effects of which can be classified under three heads: First, the common hoar frost, which occurs when the temperature sinks to the dew-point and the dew-point is below freezing; second, a dry freeze, when the temperature sinks below the freezing point and the dew-point is still lower than that mark; and, third, general freezes, when the air is thoroughly mixed and the whole mass is below freezing. The first two are usually the most damaging, but whether the dry freeze or the frost is the worst the writer does not know. Professor Brown, of the Corvallis Agricultural College, believes the most damage is done by the dry freeze, and he is probably correct in his surmise, as the thawing of a plant incased in ice would be slower than the thawing of one that was frozen without such a covering. It is a well-known fact that the slower the frozen plant thaws the less will be the damage done. In the case of the general freeze the weather is usually cloudy or partly cloudy and the winds are always somewhat brisk, if not actually strong. The thawing in such cases is always slow, and these freezes are the ones when the statement is so often made that "The damage was not so great as expected." The first two, occurring when there is but little or no wind, are due largely to radiation, and in the

¹ See Weather Bulletin T, p. 47.

last, provided it occurs when there is considerable wind, radiation plays but a small, if any, part in the process.

At North Yakima nearly all the damaging temperatures are with dry freezes, and hoar frost is seldom seen. At Boise and Lewiston frost sometimes forms, but sometimes the dew-point is too low and a dry freeze occurs. At Medford frost forms most frequently and dry freezes are rare. At all four places the general freeze occurs, and these are the most difficult to forecast on account of the dynamic heating that takes place in some of the valleys, which upsets the calculations. This is notably the case in the Boise district and to a less extent in the Yakima Valley. The general freeze occurs with a relatively low barometer and the other two classifications with a relatively high barometer and with clear or partly cloudy skies and quiet air.

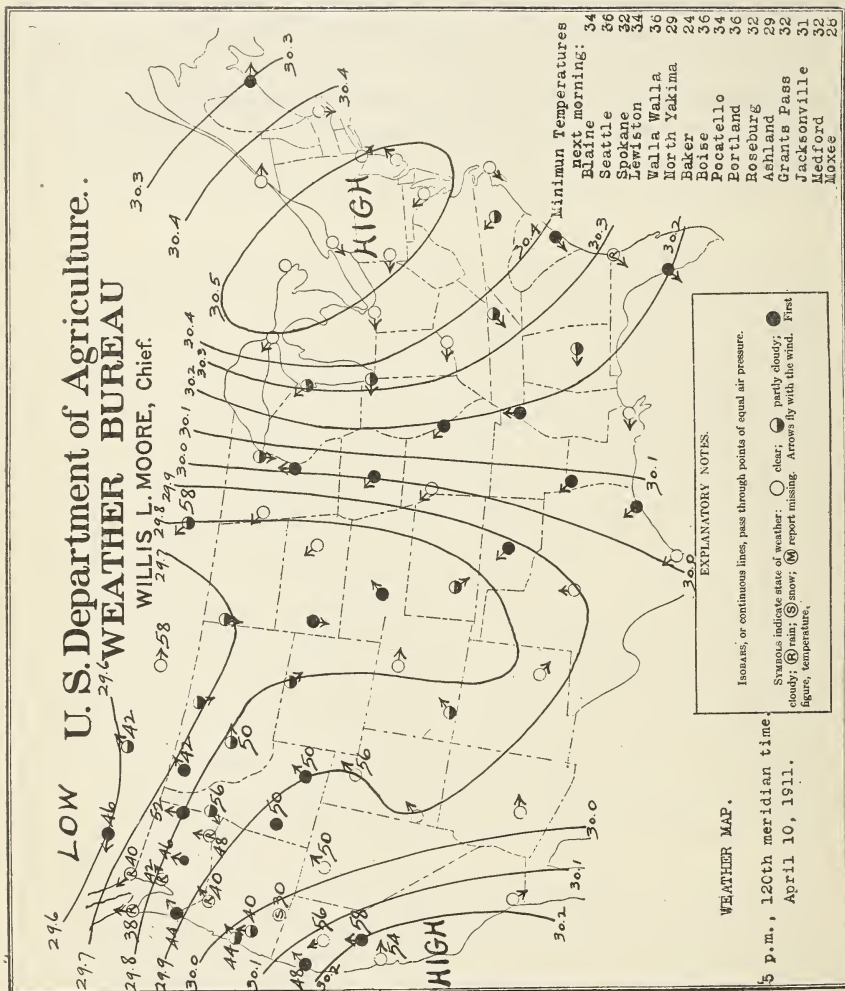
The five accompanying weather charts represent typical frost conditions, beginning with the general freeze where the whole mass of air reached a low temperature with general cloudiness and brisk southwesterly winds. As the high moved up the coast the clouds dissipated and the winds diminished in force until the air became comparatively still and radiation from the sun to the ground in the daytime and from the earth into space at night was uninterrupted. The coldest weather came during the first three days. After the high has reached its farthest point north and begins to move southeastward, the warming done in the daytime is so great that the loss at night is insufficient to cause very low temperatures.

It is not uncommon for high-pressure areas to make their appearance off the California coast, as in the case typified on Chart I, and then disappear without moving north, probably being influenced by low-pressure areas in the bight of the Pacific Ocean surrounded by the islands and coast line of southern Alaska. It is necessary for the forecaster to determine as early as possible whether or not the high-pressure area will have sufficient strength and character to assert its supremacy, and in doing this his largest asset is good judgment based upon past experiences.

Chart VI shows composite curves of the behavior of the thermometer between the time of the maximum temperature and the following minimum temperature. These traces cover only days with uninterrupted radiation, and they are interesting in showing that at North Yakima and Lewiston there are warm currents at night which interrupt the regularity of the curve, and they must be considered in making the forecasts of the degree of cold expected. Also at Medford the curve is sharpest and the Clarkston and Meridian curves are the most rounded at the time of lowest temperature. The rise from the lowest point is rapid and at all five stations the temperature is above

the freezing point by 7 a. m., except at Meridian, where the thawing weather does not set in until a half hour later.

From both the meteorological and pathological side of the problem it would seem that the best protective measures would be a combination heating device that would heat the orchards between 3 a. m. to sunrise and then throw out a dense smudge to screen the fruit from direct sunlight for three or four hours. Of course, during general freezes neither direct heating nor smudging will avail, but for dry freezes and frosts, especially the former, a smudge seems almost a necessity during the first few hours after sunrise on account of the rapid rise in temperature which the curves show at all of the places investigated.



U. S. Department of Agriculture.

LOW WEATHER BUREAU

WILLIS L. MOORE, Chief.

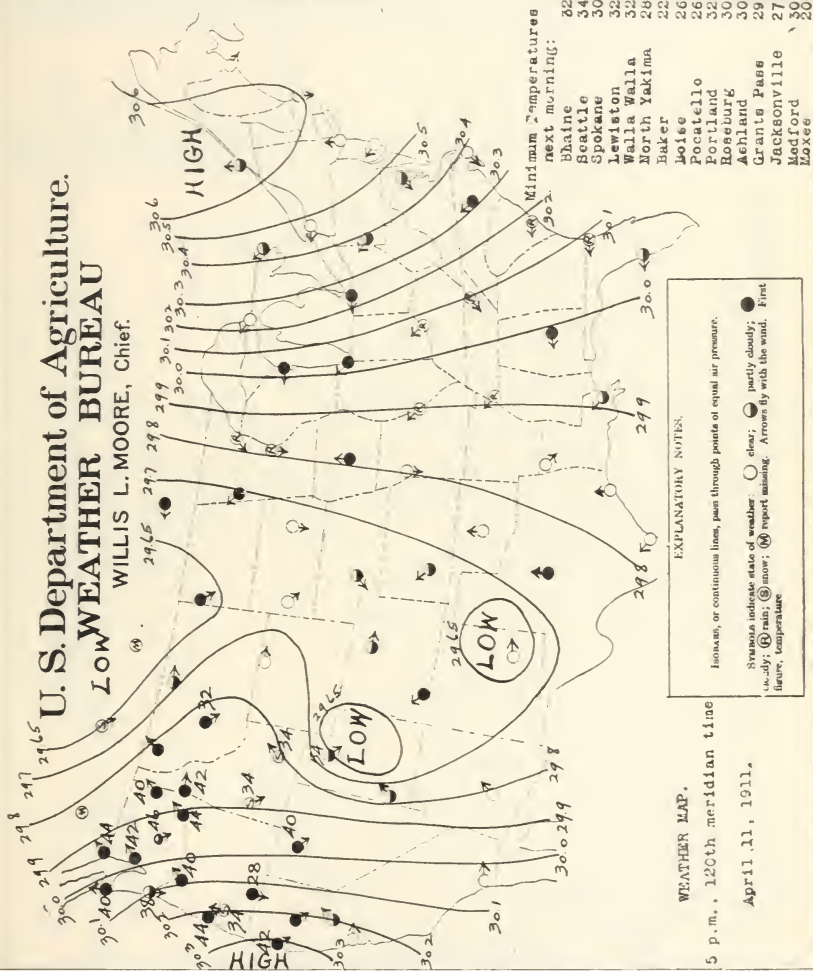
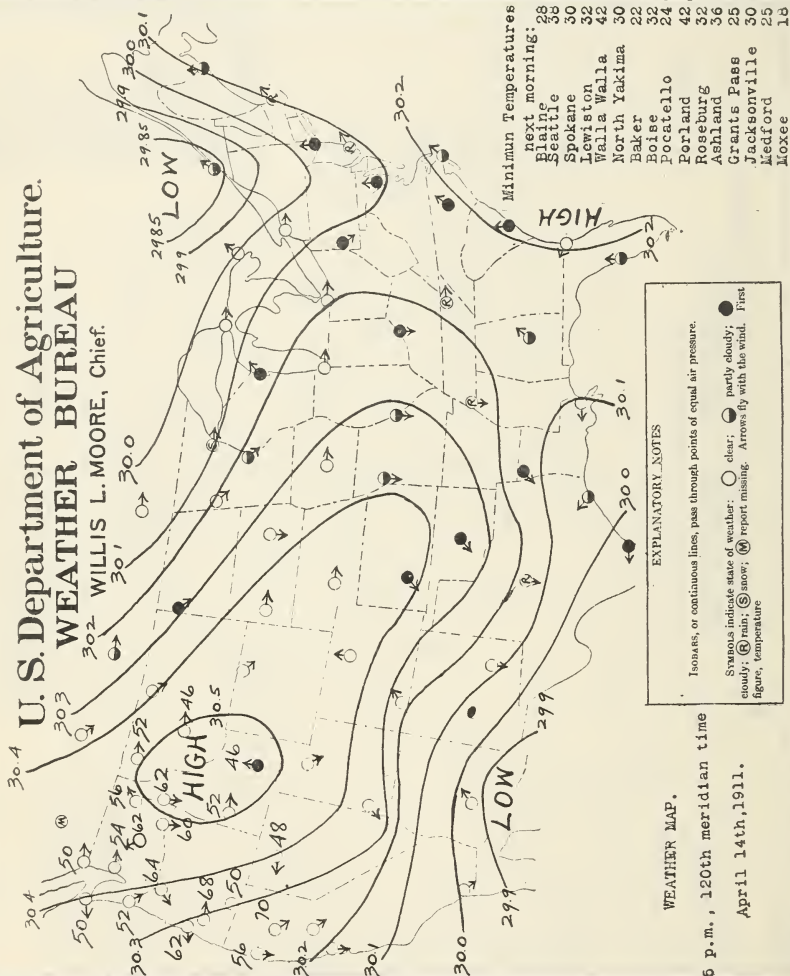


CHART II.

U. S. Department of Agriculture. WEATHER BUREAU WILLIS L. MOORE, Chief.



KILO-WATTS

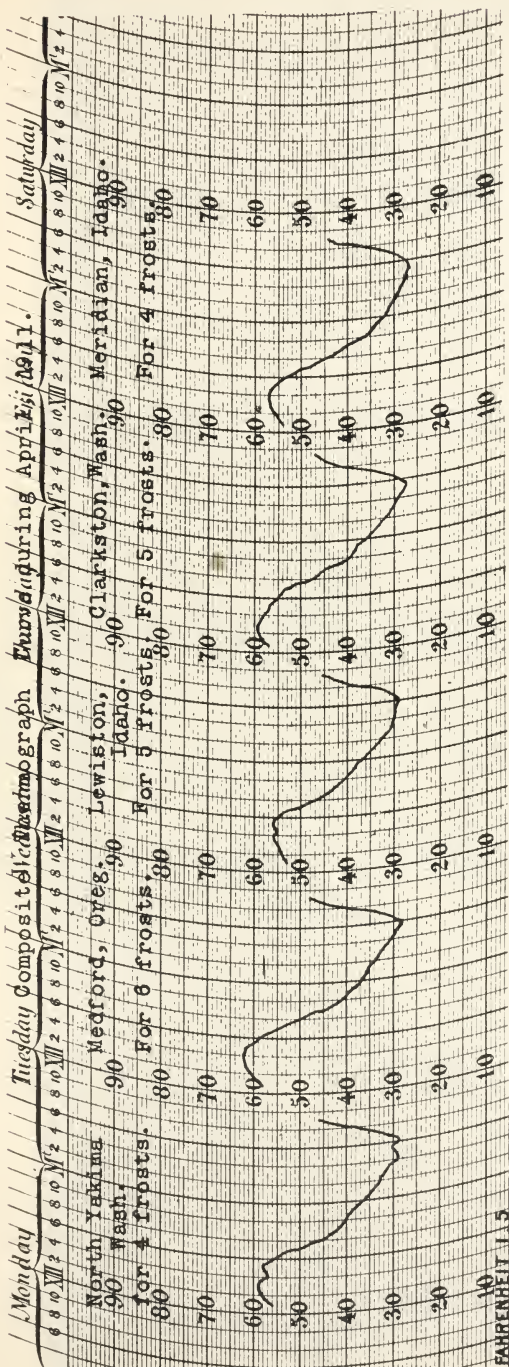


CHART VI.

